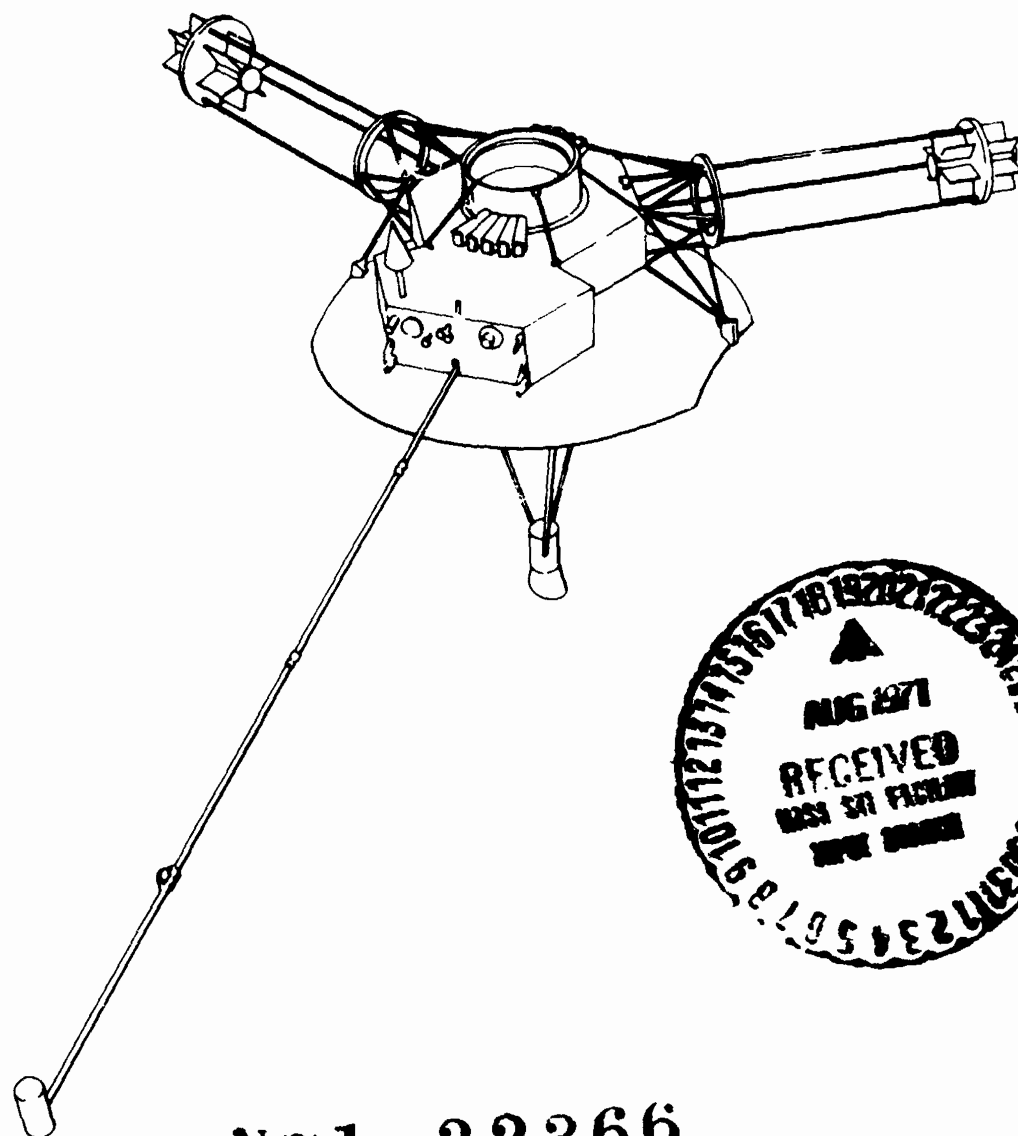
NASA SP-268

THE PIONEER MISSION TO JUPITER



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

Jupiter is one of the most impressive sights in the night sky. Ever since telescopes were invented, astronomers have studied this planet with fascination, and have revealed its bizarre and mysterious appearance and behavior. All we have learned about Jupiter has enhanced our curiosity about this unique planet that behaves most nearly like a star.

The Pioneer missions to Jupiter are especially challenging and rewarding. To reach the orbit of Jupiter, the spacecraft must travel farther than any mission man has sent into space, and must survive the unknown hazards of the asteroid belt. The reward will be detailed new knowledge of a unique planet, second only to the Sun in the hierarchy of the solar system. From the exploration of deep space as well as Jupiter we expect more can be discovered about the processes that produced a benign environment for life on the surface of the Earth.

Never before has such a broad spectrum of talents and techniques been mustered for the study of Jupiter as will participate in the Pioneer F/G Program. Part I of this monograph is a brief account of the objectives, demands, and potential rewards of this program. Part II is a highly condensed description of the complex scientific experiments to be undertaken. Part III is a similar description of the spacecraft and the management of the mission.

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CONTENTS

I

BASIC RESEARCH

Pioneers F and G are being prepared to extend studies of interplanetary phenomena beyond the asteroid belt and fly by Jupiter, the Sun's largest planet. Nearly all probing of the interplanetary medium by spacecraft heretofore has been within the orbit of Mars, a much smaller and closer planet. One Pioneer will be launched in 1972 and another in 1973 to go more than eight times as far from the Earth as Mars.

Scientific hypotheses about the outer parts of the solar system still differ because few details about them can be learned from observatories on Earth. The great belt of matter that orbits the Sun between Mars and Jupiter will be examined close up for the first time (fig. 1).

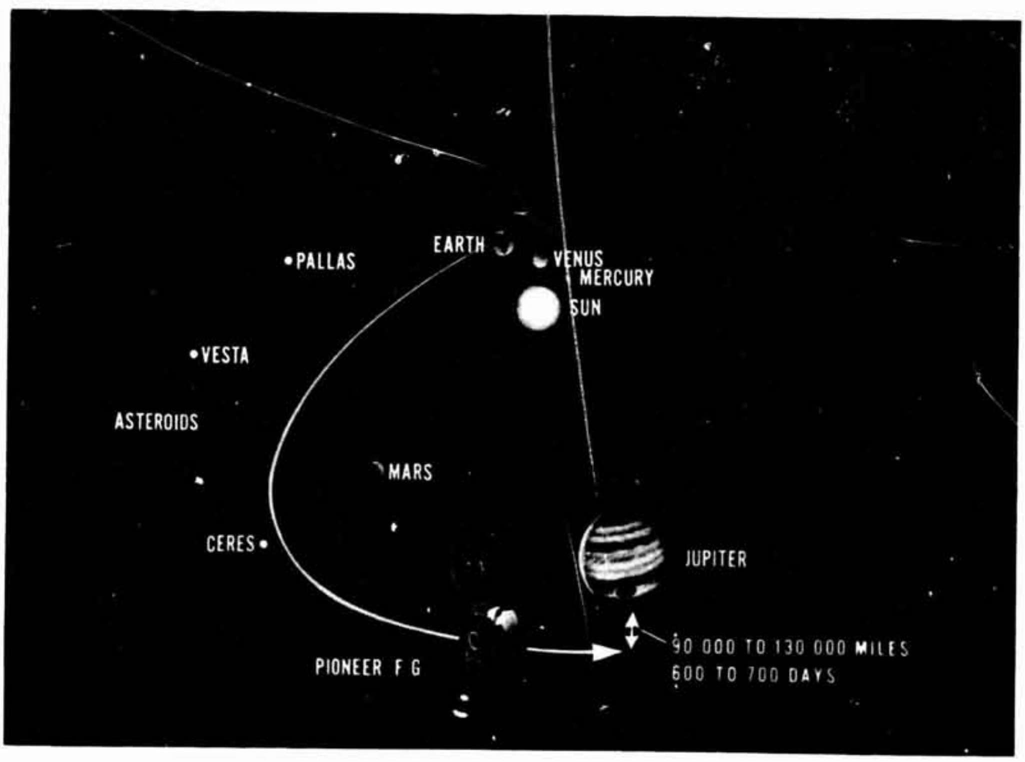

FIGURE 1.—Although asteroids constitute very little of the solar system's mass, they can be test specimens for theories of the system's origin and development. Ceres is 480 miles wide. Many others have also been given names.

So, too, will the satellites, ionosphere, and atmosphere of the second brightest planet visible from the Earth's surface. Such observations are expected to reduce uncertainties about the structure of Jupiter—a planet that has puzzled astronomers increasingly throughout recorded history.

By this extension of studies of interplanetary space, and of both the largest and many very small bodies that orbit the Sun, new insights may be obtained to the development of the Earth. More also may be learned about the physical requirements for life in the solar system, and a trail blazed for further advances in both pure and applied sciences.

OBJECTIVES

The diameter of the solar system is nearly 100 astronomical units (AU, the mean distance between the Earth and the Sun, is 92.950 million miles). The outer boundaries of this system are still poorly defined, both because they are so distant and because the interplanetary medium obscures observations of the outermost planets from the Earth. Little is known, therefore, about the interfaces of the solar system with other components of the Milky Way.

Astronomers would like to know much more about the history and status of the universe as well as the history and status of the solar system. Better deductions might then be possible regarding the universality of physical laws, feasible applications of those laws to new processes on the Earth, and the probability that life exists elsewhere. Pioneers F and G will assist scientists in their quest for basic information and engineers in their use of scientific knowledge for mankind's benefit.

Meteoroids and Asteroids

Meteorites have sometimes penetrated our planet's atmosphere, producing large craters; and billions of meteoric particles bombard the Earth every day, producing the zodiacal light visible just before sunrise and after sunset. In the asteroid belt, much more such interplanetary material orbits the Sun. Earth astronomers have identified 1776 asteroids, some of which are hundreds of miles in diameter, and have convincing evidence of the existence of many more similar bodies in that belt. These are widely believed to be debris from a planet that disintegrated in the distant past in some unknown way.

Figure 2 shows the estimated quantities of small asteroidal and cometary matter between 1 and 4 AU from the Sun. A collision with a large asteroid, or penetrations by many small bits of matter, could

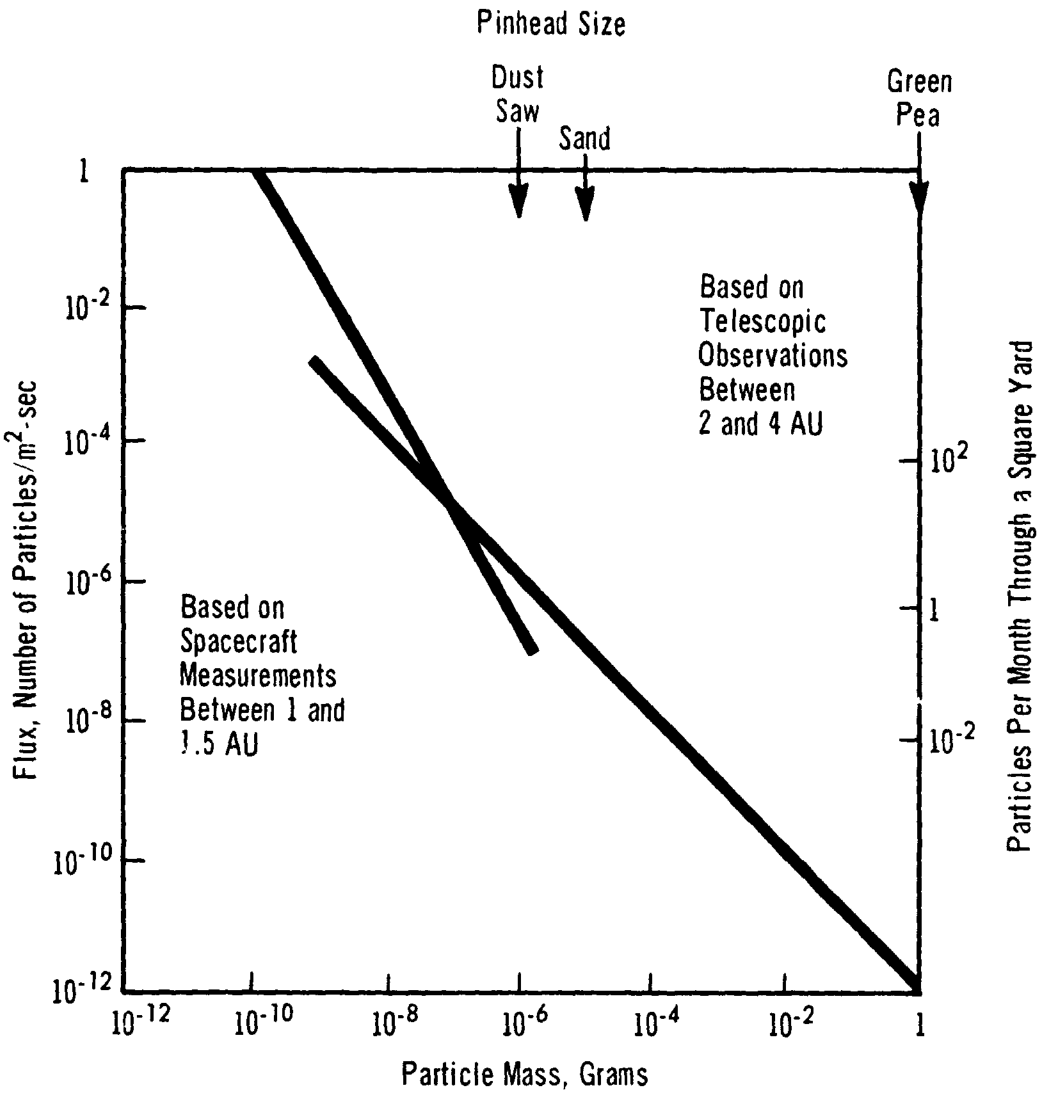

FIGURE 2.—Even submicroscopic particles can imperil spacecraft. These are estimates of the flux and mass of asteroidal and cometary material in space which will be extended and improved by measurements from Pioneers F and G of particles beyond Mars.

prevent a spacecraft from completing a passage through the asteroid belt to the orbit of Jupiter. Pioneers F and G will be attempts to survey meteoric material on both sides and within the asteroid belt and report on the composition, energies, and densities of matter there.

The Jovian Subsystem

Beyond the asteroid belt there are much larger planets than the Earth, Mars, and Venus. The nearest and most colossal of those distant giants is Jupiter, and it is also one of the most puzzling components of the solar system (fig. 3). Galileo discovered four satellites

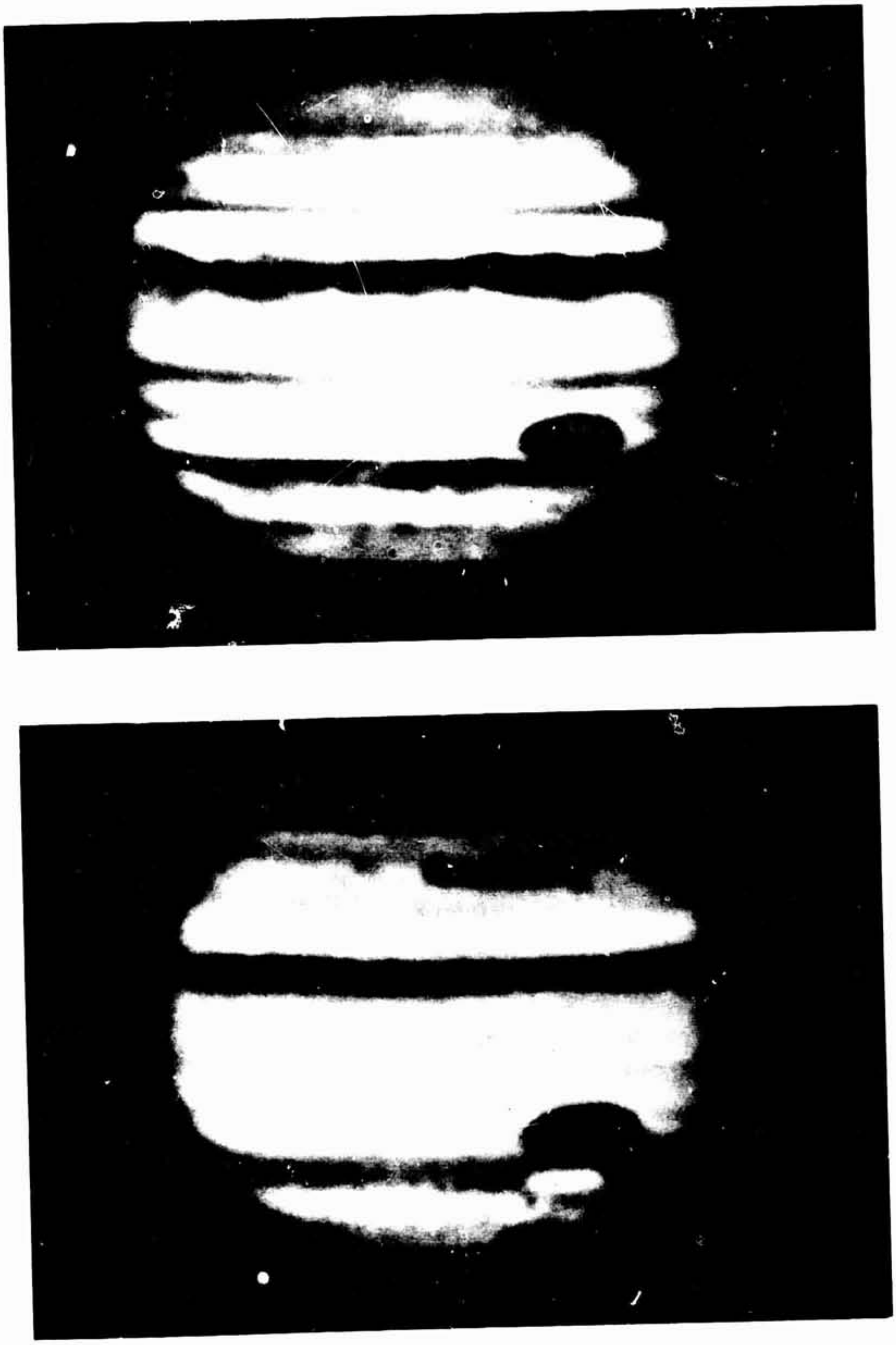

FIGURE 3.—These photographs taken from the Earth in 1969 show how Jupiter's surface is banded, its Great Red Spot, and how the poles appear to be flattened. Ganymede, a satellite of Jupiter, is visible in the lower photo and casts a visible shadow on the surface of the planet.

orbiting it, and Ole Romer discovered the finite speed of light by observations of those satellites.

Jupiter is now known to have at least 12 satellites. In this and other interesting aspects, it resembles the Sun more nearly than it does the Earth. Although it is more than 1000 times as large as the Earth, it has only slightly more than 300 times the mass of the Earth. Yet the total mass of Jupiter and its satellites perturbs the orbits of comets, asteroids, and other components of the solar system so greatly that a noted modern astronomer calls it "the dominating planet."[1] It is so radiant that another writer refers to Jupiter as "a potted star,"[2] and there is reason to believe that it, like the Moon, may prove to be a "Rosetta stone,"[3] from which much may be learned about the solar system's origin and development.

Jupiter rotates faster than any other planet of the Sun. Light and dark bands cross its golden disk (fig. 4), and a great current sweeps around its equator faster than other visible features rotate. An enormous Red Spot, about which there are many conflicting theories, floats in its deep atmosphere. The planet's appearance from the Earth constantly changes (fig. 5), and intensive studies of it from the Earth have indicated the presence of hydrogen, helium, water vapor, and ammonia and methane gas in that atmosphere (fig. 6).

Recent research also has suggested that the same chemical reactions which are believed to have preceded the appearance of life on the Earth are taking place now on Jupiter.

Jupiter, furthermore, seems to be radiating more energy than it receives from the Sun. More radio noise reaches the Earth from Jupiter than from any other source except the Sun. Bursts of radio noise from this planet sometimes are equivalent in energy to several hydrogen bombs or billions of simultaneous lightning flashes. Three distinct types of radiofrequency emissions from Jupiter have been recognized, and analysts of that noise believe that Jupiter has radiation belts (fig. 7) comparable to those discovered near the Earth by predecessors of Pioneers F and G.

"It may be," according to Dr. Robert Wildey of the U.S. Geological Survey's Center of Astrogeology, "that Jupiter has not quite finished 'falling together' into a rigid planet from the original interstellar material from which it was formed so that its power generation is essentially gravitational energy conversion."[4]

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[1] Whipple, Fred L.: *The Earth, Moon and Planets* (Harvard University Press, 1963).

[2] Firsoff, V. A.: *Exploring the Planets* (Sidgwick & Jackson, London, 1964).

[3] Rasool, S. I.: In *Astronautics and Aeronautics*, Oct. 1968.

[4] UPI, *Washington Post*. Dec. 1970.

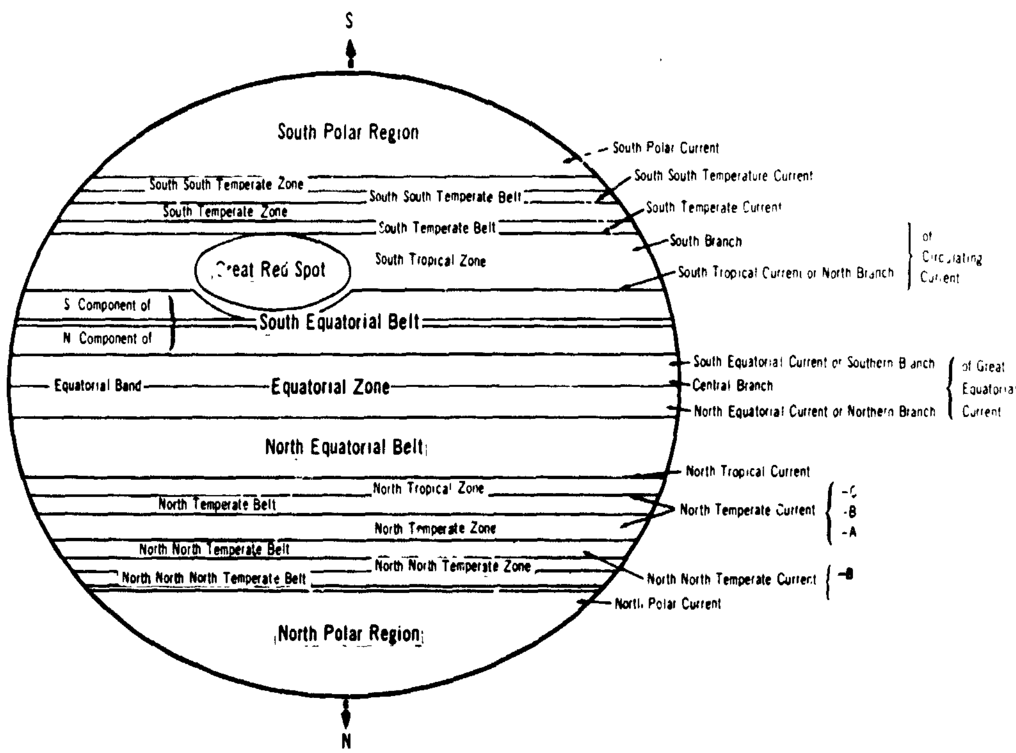

FIGURE 4.—The British Astronomical Association adopted this nomenclature to distinguish Jupiter's features. The belts are usually gray, but tinted red and blue at times. The zones usually appear yellow or creamy white.

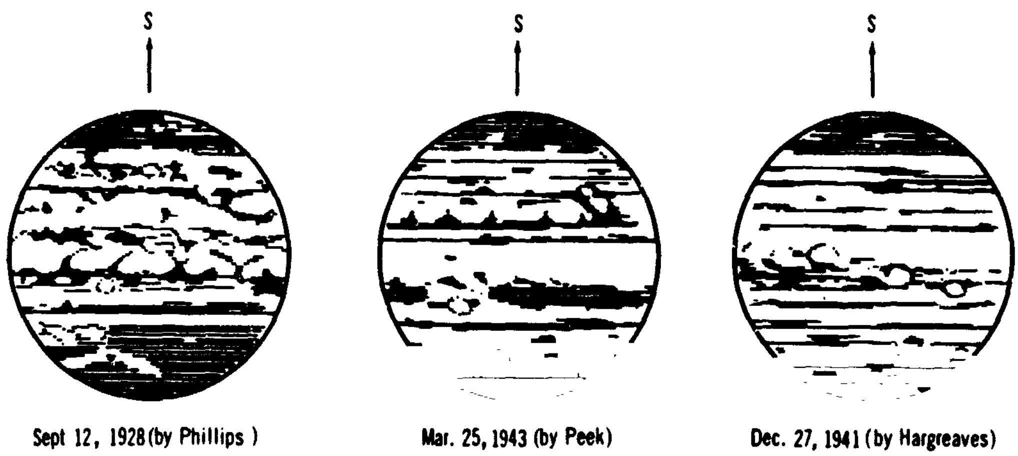

FIGURE 5.—These drawings show some of many changes that have been documented in Jupiter's face by earthbound observers. The great variety of currents, drafts, and forms in the clouds conceals the big planet's surface from optical telescopes on the Earth.

TECHNICAL FRONTIER

The relative motions of Jupiter and the Earth make it possible for the United States to send a probe out to the dominant planet only during a brief period of time every 13 months (fig. 8). At other times,

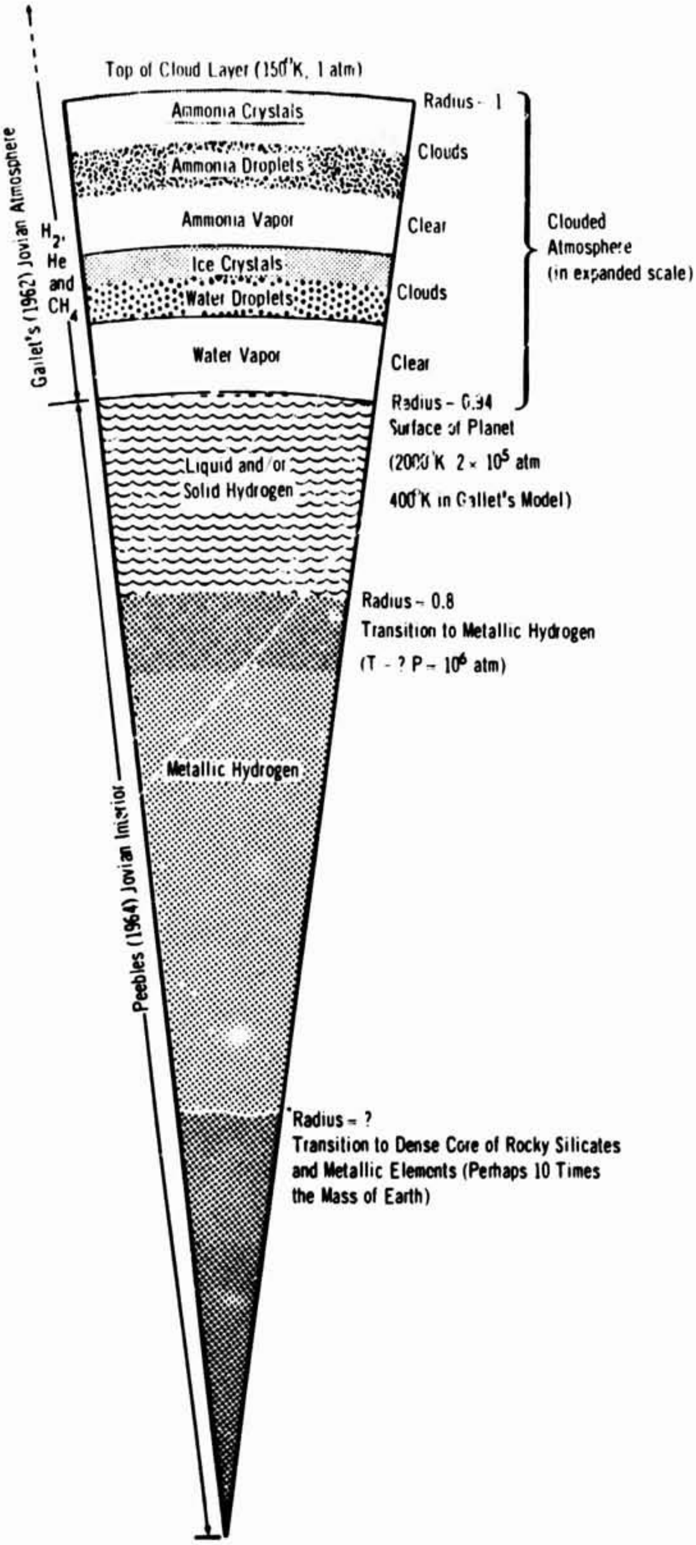

FIGURE 6.—Numerous models of Jupiter's atmosphere and structure have been conceived on the basis of limited information. This is an example of a recent model.

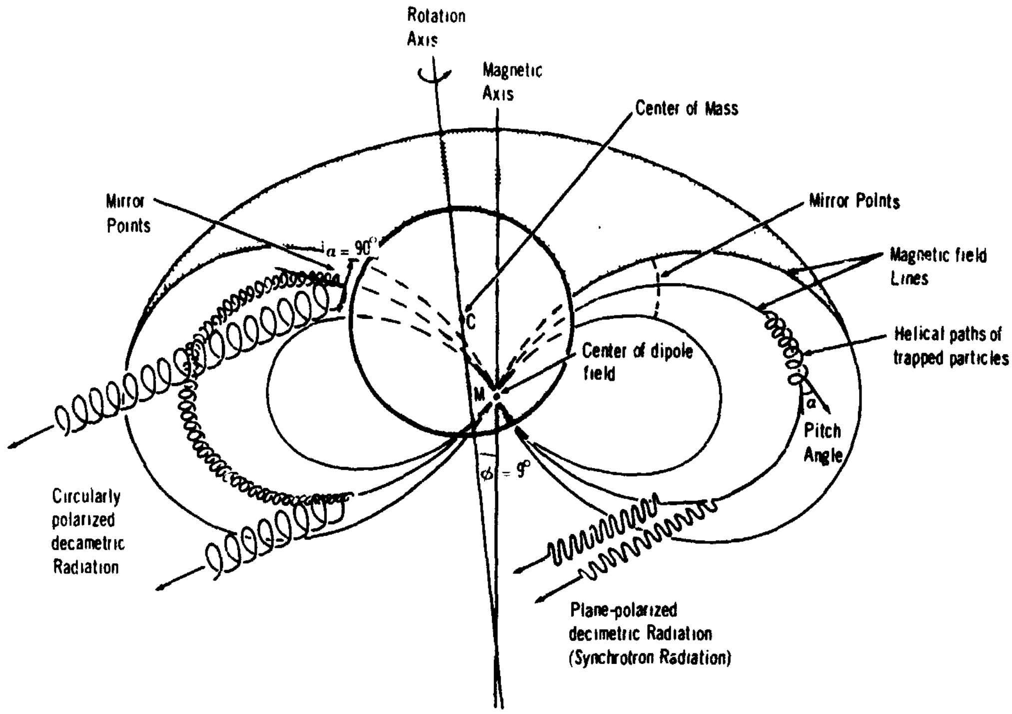

FIGURE 7.—Observations of Jupiter from the Earth have suggested that its magnetic dipole may be tilted, as shown here. Pioneer observations may help to explain how electrons are injected into the magnetosphere and accelerated to relativistic energies near the planet.

the injection velocities required for such a venture exceed the maximum now obtainable. Pioneer F is scheduled to be launched between February 28 and March 16, 1972, and Pioneer G during the next favorable period, between April 3 and 20, 1973.

Although these vehicles will attain a speed of 47 000 to 48 000 feet per second, and thereby set a new record for spacecraft, it will take each one about 2 years to reach Jupiter. They will not reach the asteroid belt until more than 4 months after being launched into the proper trajectory (fig. 9). Each one will then be in that belt for more than 6 months, on a course that will take it to the far side of the Sun from the Earth.

Pioneer F is to be guided to within about 100 000 miles of Jupiter and pass around the planet within the orbits of its satellites. The spacecraft will be behind Jupiter for less than an hour. Its trajectory will then carry it on out of the solar system.

Pioneer F's approach and passage around Jupiter will be close to the planet's equator (fig. 10). Pioneer G may be sent around the planet along approximately the same course or directed out of the ecliptic at some moderate angle for observations at a higher latitude. Each spacecraft will be close to Jupiter for only about 4 days.

The findings in those few days, nevertheless, may increase men's chances of successfully grasping future opportunities to explore the outermost portions of the solar system. The relative positions of the Earth and the planets beyond Jupiter will be such that (1) an outer-planets mission spacecraft launched in 1977 could fly past Jupiter in 1979, past Saturn in 1980, and approach Pluto, the outermost and least known planet, in 1985; and (2) a similar vehicle launched from the Earth in 1979 could pass close by Uranus in 1985 and Neptune in 1988. Equally favorable opportunities for the exploration of those distant planets will not recur for scores of years—not until the year 2152 for Jupiter, Saturn, and Pluto, and not until 2155 for Uranus and Neptune.

BENEFITS

There is reason to believe that most of the large components of the solar system were created at about the same time as the Earth, some 5 billion years ago, but how the planets attained such different states as we find them in now is far from clear. By further advances in

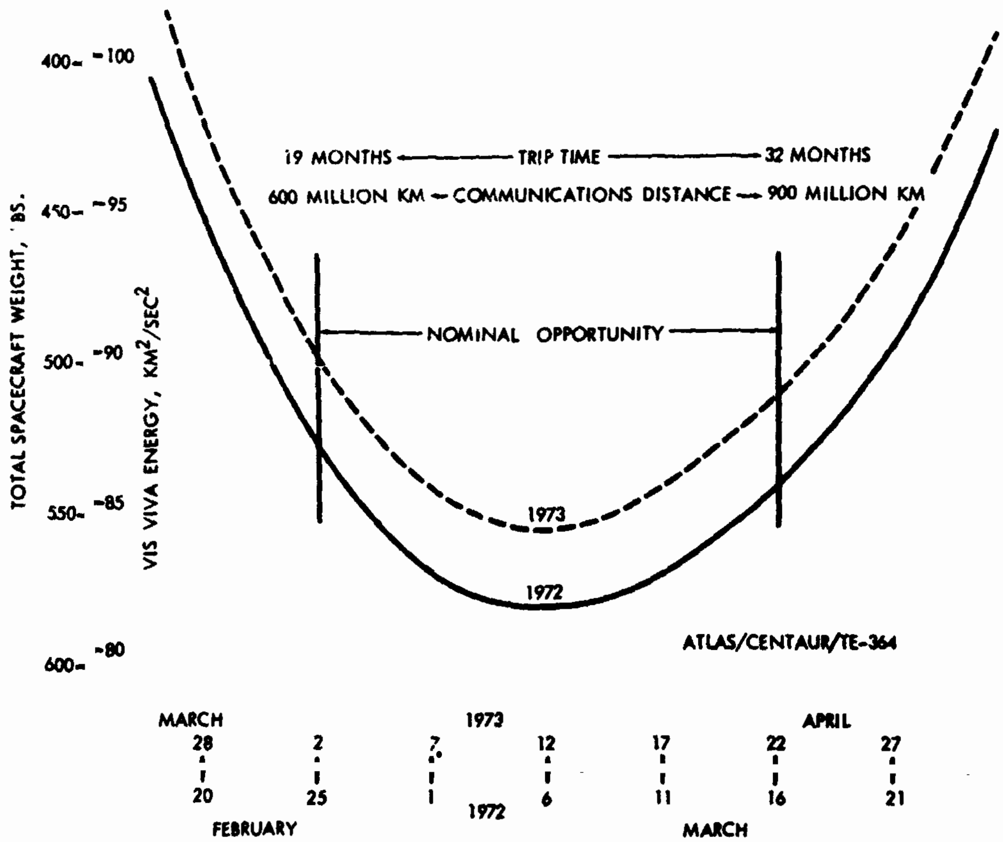

FIGURE 8.—Launching dates determine the weight possible, the energy required, the trip time, and the communications distances involved in missions to Jupiter. Pioneers F and G will exploit nominal opportunities.

planetary astronomy, scientists hope to gain greater knowledge of factors responsible for those differences, and thus achieve better understanding of the development of the Earth as a favorable abode for life.

"Life and its environment," the noted Harvard paleontologist, George Gaylord Simpson, assures us, "are interdependent and evolve together."[5] Exploration of the Moon, the interplanetary medium, and nearby planets has already yielded data helpful to life scientists as well as to the physical scientists. Increasing knowledge also has made men more aware of their responsibilities as stewards of other forms of life on Earth, and more basic information is clearly needed to meet those responsibilities intelligently, efficiently, and benignly.

Tremendous changes in the condition of the Earth unquestionably occurred before human activities became appreciable factors in determining its future. The climate is one example. No one knows, how-

[5] Quoted by Lorin Eisley in *The Unexpected Universe* (Harcourt Brace Jovanovitch, Inc., New York, 1969).

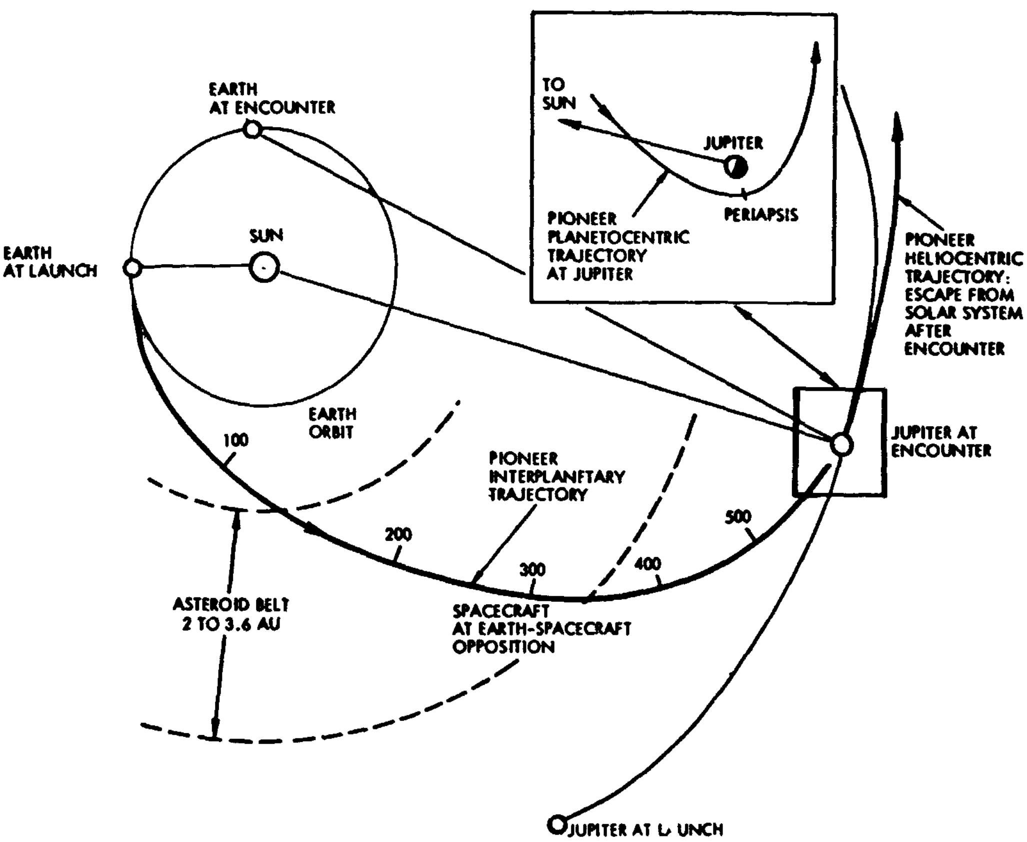

FIGURE 9.—The sidereal periods of Jupiter and the Earth differ, and the line of sight between the Earth and the spacecraft will be close to the Sun before the encounter with Jupiter. Numbers along the trajectory show the Pioneers' approximate progress in hundreds of days after being launched.

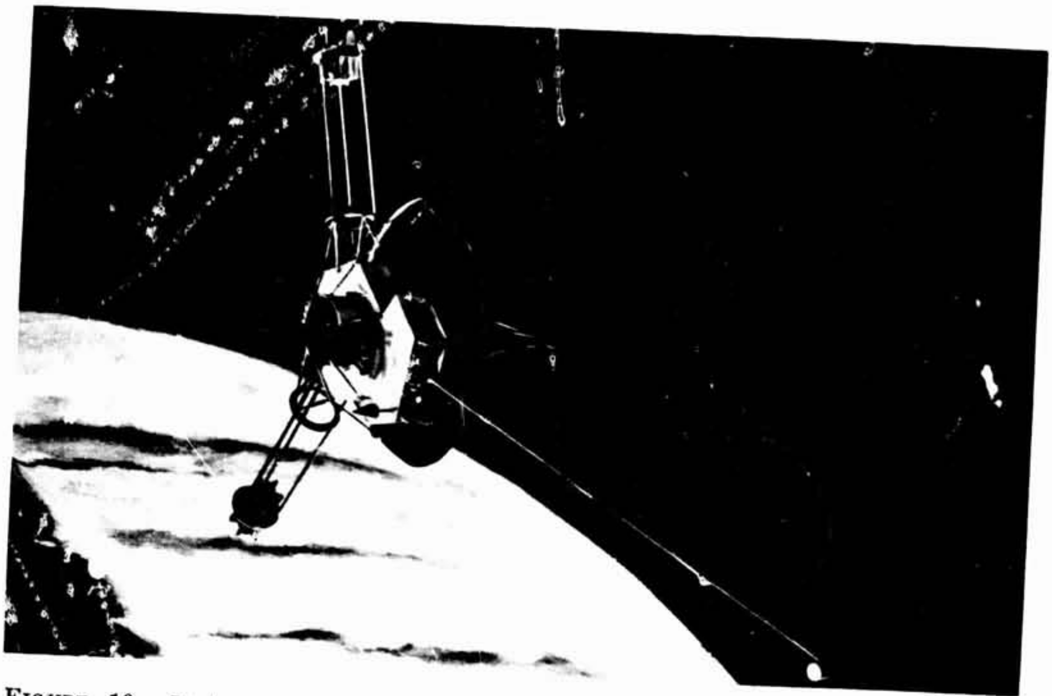

FIGURE 10.—Instruments behind the big antenna reflector on each Pioneer will be used for interplanetary research throughout much of the flight.

ever, what brought the Ice Ages about, and no scientist can now say for sure how stable the climate is at present. Yet men's work appears to have begun to affect not only the atmosphere but also the hydrosphere and the lithosphere significantly. Processes that have affected the Earth—and will continue to affect our environment, with or without human intervention—may become clearer when more is learned about the development of other planets.

Observations of the kind to be made during the next Pioneer missions will increase basic knowledge of the solar system. The data, consequently, may prove to be highly valuable to future generations in dealing with environmental problems on Earth such as have recently become of more grave concern than ever before to all well-informed people.

"There is little doubt," according to a 1968 National Academy of Sciences report, "that the more interesting discoveries in the planetary system will continue to result from space exploration in the form of probes, orbiters, or landers."[6] Spacecraft have three great advantages over ground-based telescopes: Observations are less degraded by scattered background light, much better angular resolution is attainable, and more of the electromagnetic spectrum can be used.

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[6] National Academy of Sciences: *Planetary Astronomy, An Appraisal of Ground-Based Opportunities*, 1968.

II

SCIENTIFIC EXPERIMENTS

Thirteen experiments will be performed during the Pioneer missions to Jupiter. They were chosen to exploit opportunities for close measurements both while the spacecraft are on the way to Jupiter and during the brief encounters with that planet.

Most of the experiments are closely related. Some are approaches to the same basic processes as others, but by distinctly different techniques. Several are ingenious combinations of instruments. Cumulatively, the findings are expected to provide data helpful to specialists in numerous branches of basic and applied sciences when analyzed and related.

Wide ranges of electromagnetic phenomena will be examined, and spin-scan imaging will be attempted for the first time from an interplanetary vehicle. All of the apparatus to be carried on the spacecraft has been designed to minimize its weight, volume, and power requirements. Most of the instruments and techniques, nevertheless, will be quite similar to types already successfully employed in laboratories on Earth and on spacecraft sent on shorter missions.

The data returned from Pioneers F/G, consequently, will be readily relatable to the data that scientists have been gathering for many years from their work in electronic laboratories, from optical and radio telescopes, and from other spacecraft. The findings during the Jupiter mission will also be augmented by data that will be received concurrently from other probes of interplanetary space in different parts of the solar system closer to the Earth.

Two of the 13 experiments will require no special apparatus aboard the Pioneers, and will be described here first. The other 11 will rely on reports from the spacecraft's 61.5-lb scientific payload, and will be described in the sequence in which the instruments that will be used are listed in table 1.

The two meteoroid detectors listed first in that table are relatively easy to understand, highly pertinent to further ventures into space, and will be rewarding months before either spacecraft approaches Jupiter. The next six experiments all pertain to studies of the solar

TABLE 1.—*Onboard Pioneer Experiments*

Instrument	Volume, inches (centimeters)	Total weight, pounds (kilograms)	Average power required, watts
Meteoroid detector	3 × 3 × 3 (7.6 × 7.6 × 7.6)	3.2 (1.5)	1
Asteroid/meteoroid detector	6 × 6 × 2 (15.2 × 15.2 × 5.1)	5.2 (2.4)	1.7
Plasma analyzer	11.5 × 11 × 6 (29.2 × 27.9 × 15.2)	11.5 (5.1)	4.2
Helium vector magnetometer	8 × 5 × 4 (20.3 × 12.7 × 10.1)	5.2 (2.4)	3 to 4.1
Charged particle detectors	9 × 7 × 9 (22.9 × 17.8 × 22.9)	7.3 (3.3)	2.4
Cosmic-ray telescope	6 × 6.5 × 8 (15.2 × 16.5 × 20.3)	6.9 (3.1)	2.4
Geiger-tube telescope	6 × 4 × 5 (15.2 × 10.1 × 12.7)	3.6 (1.6)	0.8
Trapped radiation telescope	5 × 6 × 6 (12.7 × 15.2 × 15.2)	3.8 (1.7)	2.2
Ultraviolet photometer	4 × 4 × 5 (10.1 × 10.1 × 12.7)	1.4 (0.6)	1
Infrared radiometer	9 × 6 × 4 (22.9 × 15.2 × 10.1)	4.3 (2.0)	1.3
Imaging photopolarimeter	7 × 7.5 × 10 17.8 × 19.0 × 25.4)	9.1 (4.1)	3.5

wind, radiation from outside the solar system, and concepts of the maze of charged particles in space. The last three devices, as listed in the table, will both further clarify such concepts and reduce uncertainties about Jupiter's role in the solar system.

EARTH-BASED EXPERIMENTS

One of the two experiments for which Pioneers F and G will not carry any special apparatus will be an analysis of the tracking data (fig. 11). The techniques will resemble those already used successfully with data from Mariners on flights to Mars and Venus. The Jet Propulsion Laboratory in Pasadena, Calif., developed these methods, which require the use of large computers, and a new advanced central data-processing system will be operational in Pasadena for initial use during the Jupiter mission.

The other Earth-based experiment will be a study of celestial mechanics and an examination of the effects of the Sun and Jupiter on radio transmissions in the S-band of frequencies (between 1.55 and 5.2 gigacycles). These frequencies will be used increasingly in the next few years. Findings in both experiments will be helpful in attacking unsolved scientific problems and further realization of the potentialities of spacecraft as research vehicles.

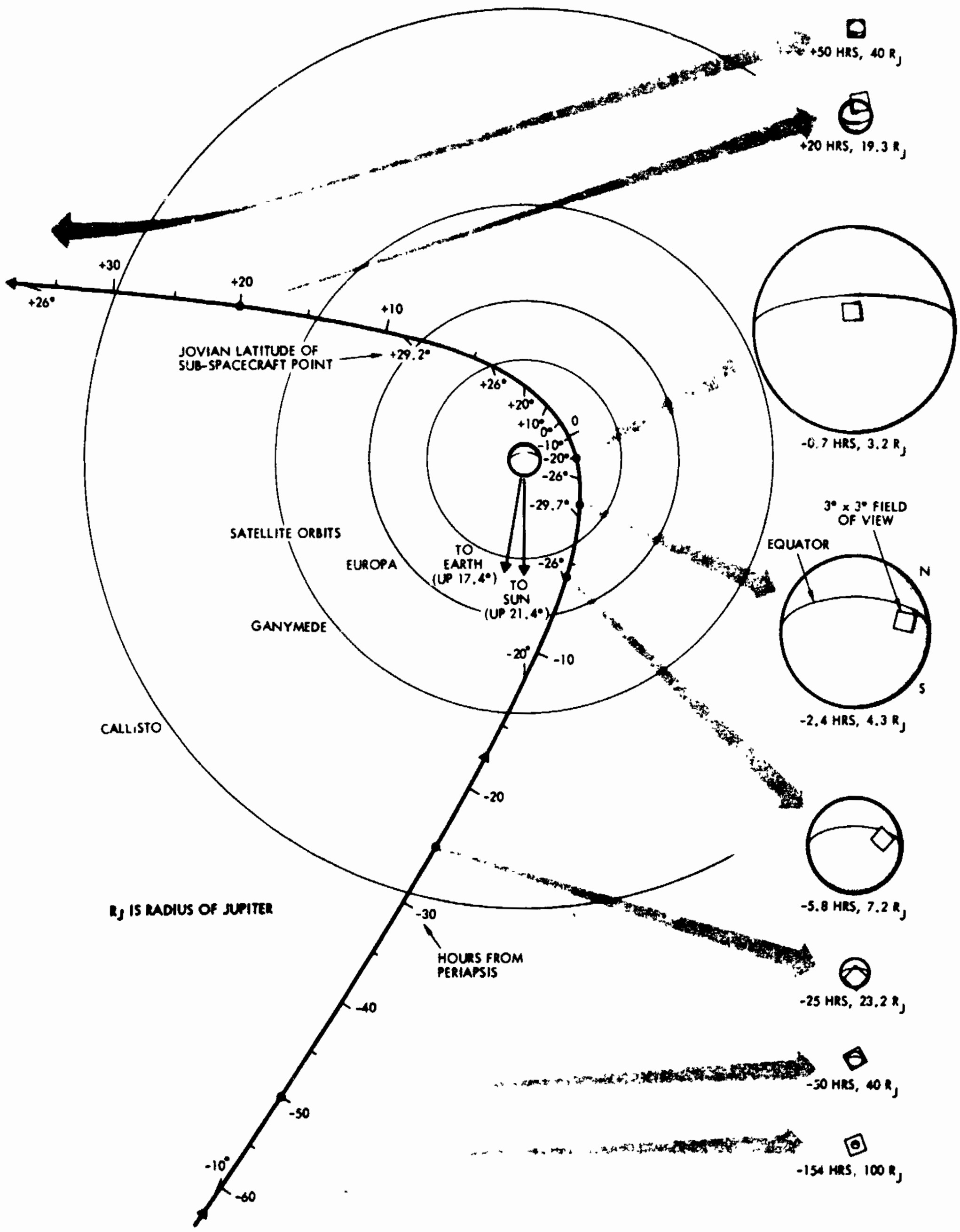


FIGURE 11.—Investigators of celestial mechanics and S-band occultation will derive information from tracking data. This is a typical encounter with Jupiter as envisioned.

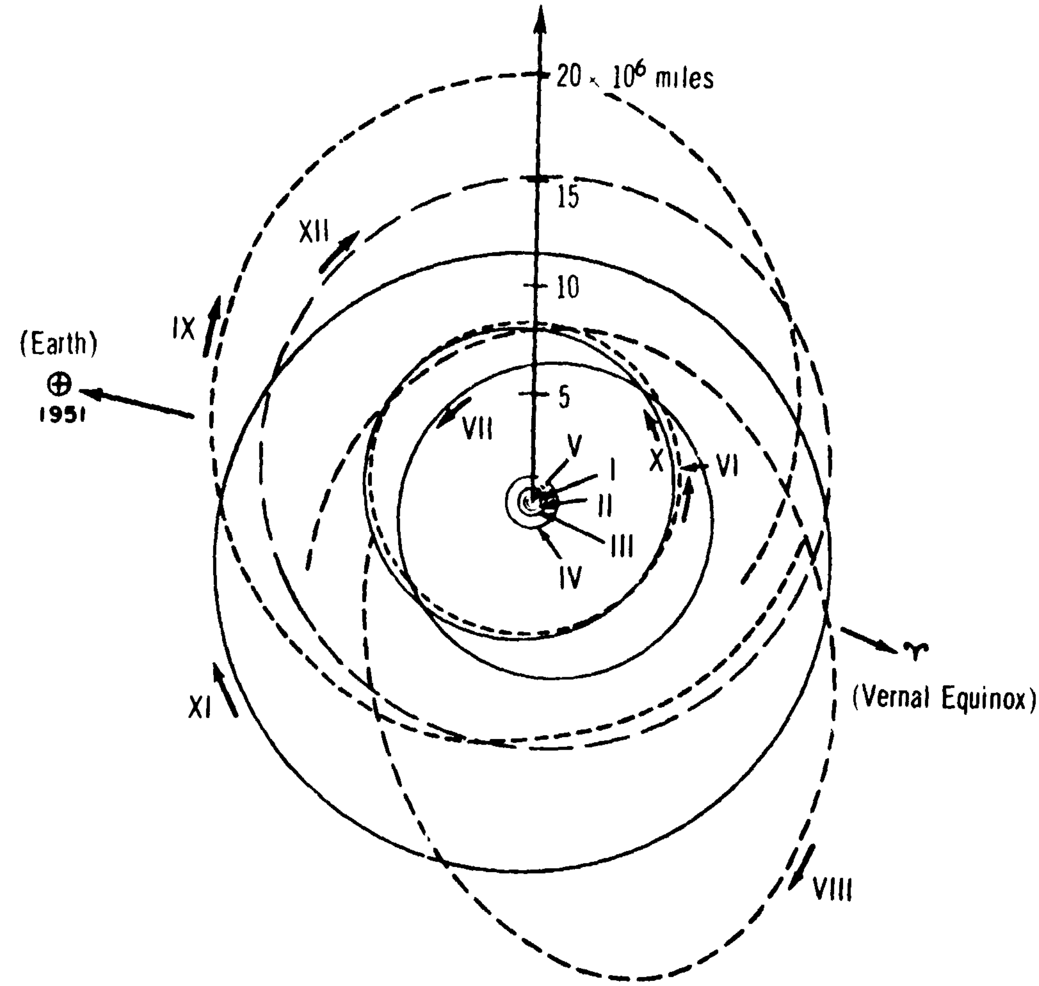


FIGURE 12—Jupiter's satellites differ in their masses and orbits. Five constitute an inner system: seven others have been discovered in an outer system since 1900.

Celestial Mechanics

Two Jet Propulsion Laboratory researchers, Dr. J. D. Anderson and C. W. Null, will direct an effort to determine the gravitational forces to which the Pioneers are subjected in the course of their flights. This will be done by a computer analysis of regular two-way Doppler tracking data, acquired throughout the mission, augmented by optical and radar position data.

Such an analysis may enable the investigators to determine the mass of Jupiter more accurately than has been possible from observatories on the Earth. Uncertainties regarding the masses and orbits of some of Jupiter's satellites may also be reduced. The geocentric coordinates of the mass of Jupiter will be used to compute the heliocentric orbit of the planet more precisely, and the harmonics of its gravity field will be studied. Anderson and Null hope to improve current calculations of the mass of Jupiter by at least a factor of 10, and those of the total mass of Jupiter and its many satellites (fig. 12) by at least a factor of 6.

S-Band Occultation

In another computer analysis of the Jupiter mission tracking data, an atmospheric physicist who has long been immersed in studies of Jupiter, Dr. S. I. Rasool of the Goddard Space Flight Center, will be associated with a Jet Propulsion Laboratory team headed by Dr. A. J. Kliore. The Earth's ionosphere, the interplanetary medium, the Sun's corona, and Jupiter's ionosphere will all affect the S-band transmissions received from the Pioneers. The effects of the Earth and interplanetary phenomena are expected to be quite stable at the time of the Pioneer mission, so these investigators hope to isolate good measurements of the solar and Jovian effects.

All of the tracking data will be recorded on magnetic tape. Parts of it then will be processed with a computer to extract the particular data sought in this experiment. The data received while the line of sight between the Earth and the spacecraft is near the Sun will be used to gage the solar effects on the radio communications. Similarly, the signals received while the spacecraft is nearing and emerging from behind Jupiter may disclose the effects of its ionosphere on the transmissions from the vehicle.

From refractive index profiles of the distant planet's ionosphere obtained when the spacecraft are occulted by it, the researchers expect to derive profiles of the electron density around Jupiter. Such findings can be combined with temperature data from other sources to find the ratio of helium to hydrogen in Jupiter's atmosphere.

Estimating the ratio of those two simple elements is a formidable task for astronomers dependent on observations from afar. Determining it would be extremely helpful to theorists trying to envision the huge planet's development and structure. Hence this will also be an objective of investigators with apparatus aboard the Pioneers.

METEOROID ASTRONOMY

Meteoric material has long been recognized as a significant component of the solar system from which much may be learned about the whole system's origin and history. Researchers in this branch of astronomy have been especially handicapped thus far by the difficulties that are inherent in observations from great distances of objects that vary extremely in mass. Virtually all that is now known about meteoric material has been learned from particles within or near the orbit of the Earth. Meteoroids are expected to be more plentiful and diverse in the asteroid belt through which the Pioneers must pass to reach Jupiter.

Two of the experiments that will require special devices aboard the spacecraft will be efforts to detect and learn more about meteoric material twice or more as far from the Sun as the Earth's orbit. One of these experiments is expected to reveal how many particles the spacecraft collides with that are too small to be detected visually. The other will be an initial optical survey of larger fragments of matter (greater than 10^{-6} grams mass, about 0.006 centimeter in diameter) that are observable from the vehicles. (The immensity of the task of taking a census of meteoric material whirling around the Sun prompted the designers of the latter experiment to name their apparatus "Sisyphus," after an ancient Corinthian king whose legendary punishment in Hades was to roll a heavy stone up a hill only to have it roll back down again and again forevermore.)

Meteoroid Detector

Dr. W. H. Kinard and four coinvestigators at the Langley Research Center will be the experimenters mainly concerned with the encounters between the two Pioneers and very small bits of matter during the long flights. For this experiment, panels of pressurized cells will be mounted on each of the Pioneers (fig. 13), and penetrations of those cells will be counted. The rate at which pressure is lost from a cell will indicate the size of the hole made, and thus the mass and incident energy of the particle responsible will be learned. By combining such findings with trajectory data, the researchers will calculate the spatial density of small meteoroids.

Each panel of cells full of gas attached to the spacecraft for this experiment will consist of a 1-mil-thick and a 2-mil-thick sheet of stainless steel. These will be welded together the way that an air mattress is made, to leave a great many small pockets of gas between them. Whenever a pocket is punctured and gas escapes, a cold cathode device will note the loss.

On Pioneer F the 1-mil-thick side of this novel kind of "gas mattress" will be exposed to the interplanetary medium. Penetrations of the cells from that side will indicate encounters with meteoroids having masses of 10^{-9} grams or more. On Pioneer G the outer, exposed side of the gas mattress will be the 2-mil-thick sheet of stainless steel. Penetrations of it will indicate collisions with somewhat more formidable particles, having masses of 10^{-8}-or-more grams. Thus the range in mass of small particles on both the

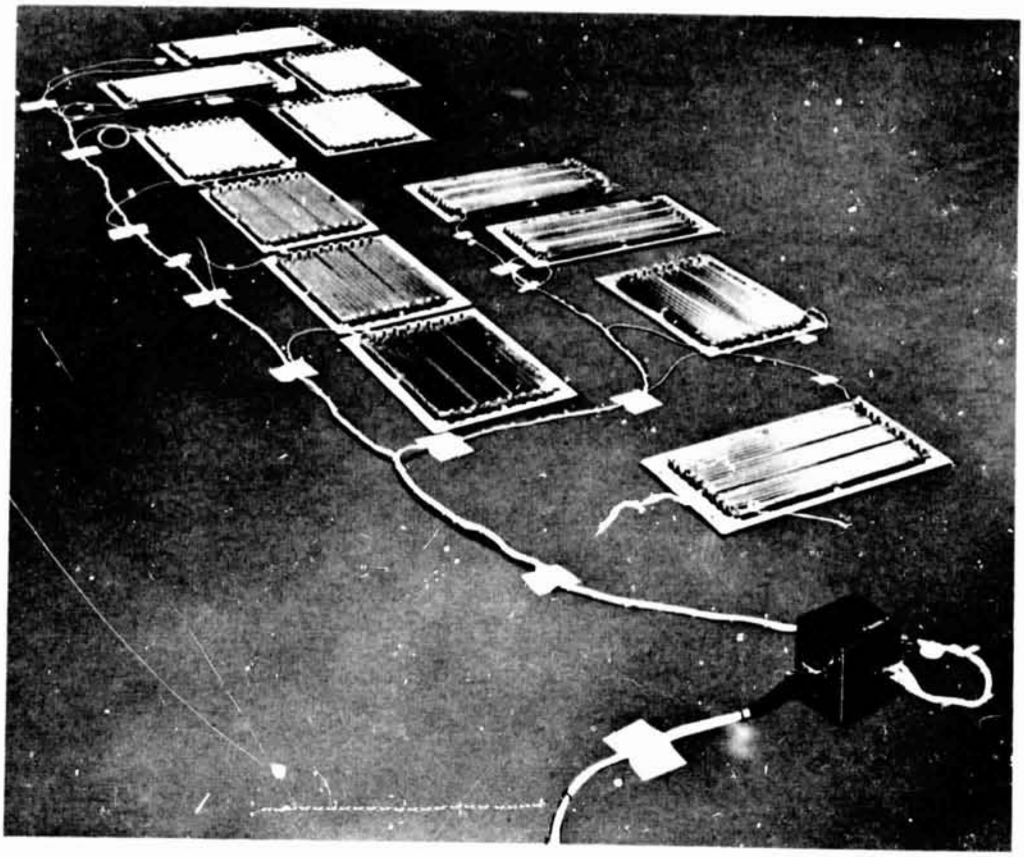


FIGURE 13.—Twelve panels, each containing 18 pressurized cells, will be mounted on the back of the antenna dish for the Langley meteoroid detection experiment. Five square feet of the exposed surface of each Pioneer will be covered with such sensors.

inner and outer boundaries and within the asteroid belt may be ascertained for the first time.

Asteroid/Meteoroid Detector

This apparatus (the device dubbed "Sisyphus") will be used to look for particles ranging upward in mass from 10^{-6} grams at the same time that smaller particles are being counted by the punctures they leave in test panels. It will detect asteroids and meteoroids by the solar light that they reflect and scatter. Four independent telescopic subsystems within it will provide four overlapping fields of view for photomultiplier tubes. The ranges and velocities of optically observable particles will be found by timing the entries and departures of their reflections in those four fields of view.

The General Electric Co.'s Space Division developed this detector and the investigators responsible for its use will be Dr. R. K. Soberman of that company and H. A. Zook of the Manned Spacecraft Center. The Pioneer flights will be trial runs for the asteroid/meteoroid detector and its developers hope that it will be found useful also on other satellites, both in orbits near the Earth and on missions to distant planets. Cometary material may be distinguishable from other particles in the interplanetary medium with this detector.

Although interplanetary particles constitute only a small fraction of the mass of the solar system, they are a significant, difficult-to-measure component. By categorizing and finding the masses of individual particles between the Earth and Jupiter, astronomers will gain a better understanding of the true nature of the system's meteoric complex. Engineers responsible for the design of future probes of deep space will also benefit from the findings in the two experiments just described. Overestimation of the possibility of encounters with destructive particles could impose unnecessary weight penalties on the performance of costly spacecraft in the future. Underestimation of the hazard could increase the chances of failures because of collisions. More accurate estimation of the possibility should be possible in the light of Pioneer data.

SOLAR-WIND STUDIES

Most of the scientific experiments requiring apparatus on the spacecraft will be focused mainly on phenomena that no one knew anything about until this century. Men observed meteors and comets long before the solar wind, cosmic rays, and belts of radiation near the Earth were discovered. Studies of these three dynamic factors in events within the solar system already have been enlightening to scientists, and the next six experiments to be described are expected to yield additional helpful data regarding them.

A stream of highly ionized, electrically charged particles continually sweeps by the Earth from the Sun. Its effects are manifested at times in the performance of electrical systems on the Earth, and it is suspected of being a factor in the determination of long-term weather cycles. Particles in this wind are trapped in radiation belts by the Earth's magnetic field, and account for the aurora borealis and other phenomena that baffled scientists and engineers until those belts were found. Much of what is now known about the solar wind has been discovered by sending spacecraft out into it, and the Jupiter mission will extend this research to more distant realms.

Plasma Analyzer

Some of the most important advances in plasma physics since 1960 have resulted from the work of the Ames Research Center group led by Dr. J. H. Wolfe.[7] These specialists will be in charge of a plasma analyzer on board the next two Pioneers. It will be the heaviest and most bulky item in the scientific package that the spacecraft will carry. It will be used both to study the spatial and temporal characteristics of interplanetary plasma and to investigate the interaction of the solar wind with the magnetic field of Jupiter. With this monitoring device, the Ames group expects to find the flow directions and flux levels at various energies in the plasma in previously unexplored portions of the solar system. At the farthest distances, the analyzer will be used to search for signs of the solar-galactic boundary.

It will operate similarly to a cathode-ray tube, but solar plasma will take the place of an electron gun (fig. 14). Ions and electrons will enter a pair of detectors from a window in the instrument housing. Throughout most of the long Pioneer flights that window will face backward toward the Earth and Sun, and the Sun will be within the field of view of the plasma analyzer.

[7] Hartman, Edwin P.: *Adventures in Research*, NASA SP-4302, p. 477.

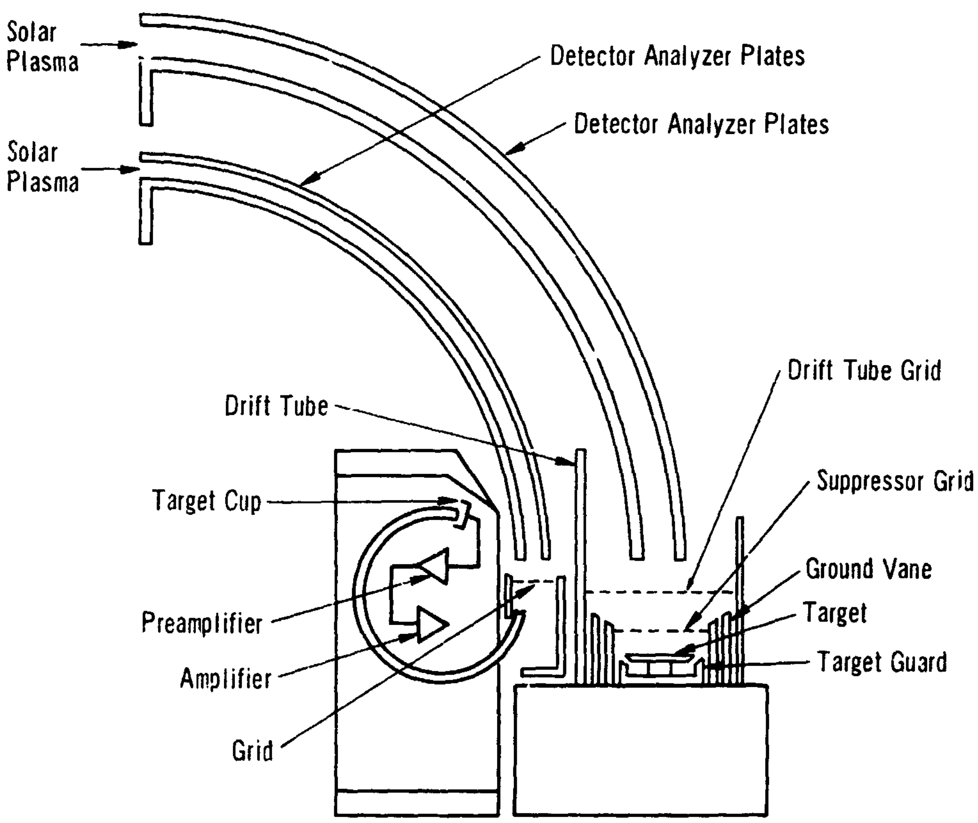


FIGURE 14. Solar plasma will be admitted to two sets of detector plates from the left here, through apertures facing the Sun. Analytical apparatus will function like a cathode-ray tube with electrostatic deflection.

In each of its two detectors, particles will be deflected by an electrostatic field between quadrispherical plates. Those curved plates will provide the desired resolution of particle energies, densities, and incident angles. One detector will measure ion energies in ranges between 100 and 8000 electron volts, and the other in ranges from 100 up to 18 000 electron volts.

Helium Vector Magnetometer

Magnetic fields affect the plasma and alter its course as it flows outward from the Sun to the orbits of planets. Beyond the orbit of the Earth those fields become weaker, but in the vicinity of Jupiter and its satellites they evidently regain strength. To map magnetic fields for long distances and over a wide dynamic range, the Pioneers will carry a helium vector magnetometer (fig. 15) for Dr. E. F. Smith of the Jet Propulsion Laboratory and six coinvestigators.

This magnetometer will be an advanced version of an extremely stable device that two Mariners on shorter missions already have

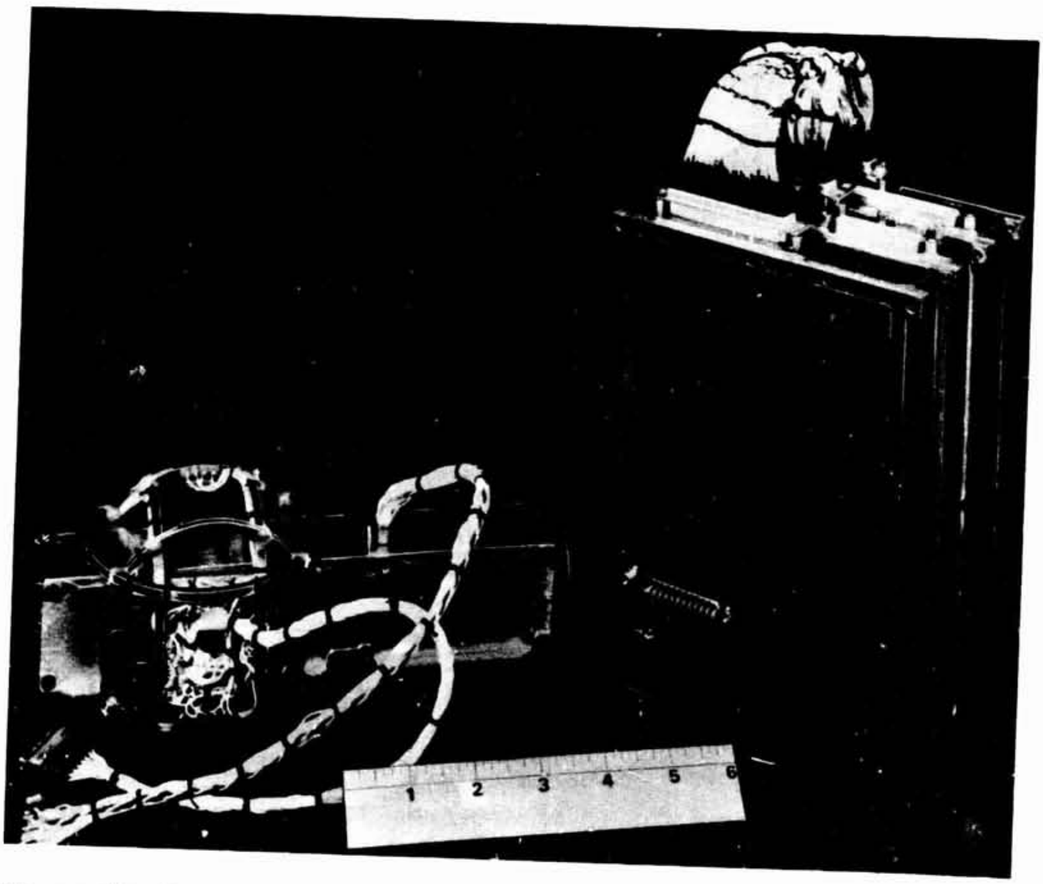


FIGURE 15.—The helium vector magnetometer's sensor, at the left, will provide the input to the electronic system at the right, in which data will be processed for transmission to the Earth.

carried for the plasma physicists. Its sensor will be a cell filled with helium and subjected to radiofrequency excitation and infrared optical pumping. The changing magnetic fields through which the spacecraft passes will cause modulations in the helium gas. These will be noted to obtain the desired data.

Weak as well as strong fields can be measured with such a sensor, and this magnetometer is expected to measure them in range from about 2.5 gamma to about 1.43 gauss. To obtain good measurements of the weak parts of interplanetary fields, magnetic fields reaching the sensor from the spacecraft must not exceed 0.1 gamma. Hence the sensor for this experiment will be on the outer end of a long mast protruding from the body of the spacecraft. Extreme care had to be taken in designing and developing the next two Pioneers (described in part III) to achieve this figure.

Data about the magnetic forces that affect the solar wind will be complementary to detailed data about its composition. Together, the plasma analyzer and the helium vector magnetometer can tell scientists much more about the interplanetary medium than is now known.

There are still many uncertainties in astronomers' minds about that medium and all of the planets beyond Mars. The outer boundaries of the solar system are still vague, and the interactions there between it and other parts of the Milky Way are still puzzling. Although the Sun's influence extends far beyond Jupiter, studies of the solar wind in that powerful planet's orbit will be helpful to theorists striving to envision the system as a whole. So, too, will the next two experiments to be described here.

COSMIC-RAY ASTRONOMY

Along with radiation from the Sun, radiation reaches the Earth from sources outside of the solar system. The particles in it are samples of matter from other and much larger parts of the galaxy. Many of them have energies higher than can be attained yet in any known way on the Earth's surface. Submicroscopic charged particles in cosmic rays, traveling at nearly the speed of light, collide and shower the Earth with small secondary particles.

Since the discovery of cosmic rays early in the 1900's, many ingenious and costly efforts have been made to determine their composition, account for their energies, and locate their sources. This research has contributed notably not only to advances in astronomy but also to discoveries in nuclear physics.

Two of the important experiments performed with apparatus aboard Pioneers F and G will be extensions of cosmic-ray studies.

They are expected to be helpful in interpreting the data acquired in previous work and relating cosmic radiation to other phenomena. One will be focused on the composition of the charged particles, and in the other the energy spectra of cosmic rays will be emphasized. Data obtained as a function of distance out to the orbit of Jupiter in this pair of experiments should both increase men's knowledge of mechanisms within the solar system and broaden the basis for conclusions regarding interstellar space.

Charged Particle Detectors

Two of our country's leading authorities on the sources and courses of cosmic rays are Prof. John A. Simpson of the University of Chicago and Dr. F. B. McDonald of the Goddard Space Flight Center. Professor Simpson will be the principal investigator in one Pioneer study of the life history of cosmic rays in the solar system and Dr. McDonald in another one.

While the spacecraft are on their way to the encounters with Jupiter, charged particle detectors for Prof. Simpson's group will note how streams of particles from solar flares spread out and overtake one another several AU from the Sun. Later in the mission the same detectors will be used to obtain data regarding the Jovian radiation belts for comparison with findings regarding the Earth's radiation belts.

In addition to a charged particle telescope having the same resolution as one now in an Earth orbit, the apparatus for this experiment will include an electron detector, a pair of fission detectors, and a proton detector. With this set of devices, the radial and transverse gradients and the anisotropy of particles in cosmic rays will be measured. Fields between Mars and Jupiter then can be mapped with more certainty.

Cosmic-Ray Telescope

Dr. McDonald's team will include Prof. William R. Webber of the University of New Hampshire and Dr. K. G. McCracken of the Commonwealth Scientific and Industrial Research Organization of Australia. They will use instrumentation similar to that aboard an Interplanetary Explorer that was launched in the spring of 1971.[8] It will be a coordinated set of solid-state detector telescopes that will be comprehensive, redundant, and selfcalibrating. This apparatus, carefully designed to maximize its diagnostic power,

[8] Pre Launch Mission Operation Rept. No. S–861–71–08, Mar. 1, 1971.

will consist of one telescope for high-energy particles and two for low-energy particles (fig. 16).

Table 2 shows the variety of particles and the energy ranges with which these investigators will be concerned. They will analyze energy spectra, charge composition, and general flow patterns of solar, galactic, and Jovian energetic particles. In the vicinity of Jupiter, they will study the angular distribution of hydrogen,

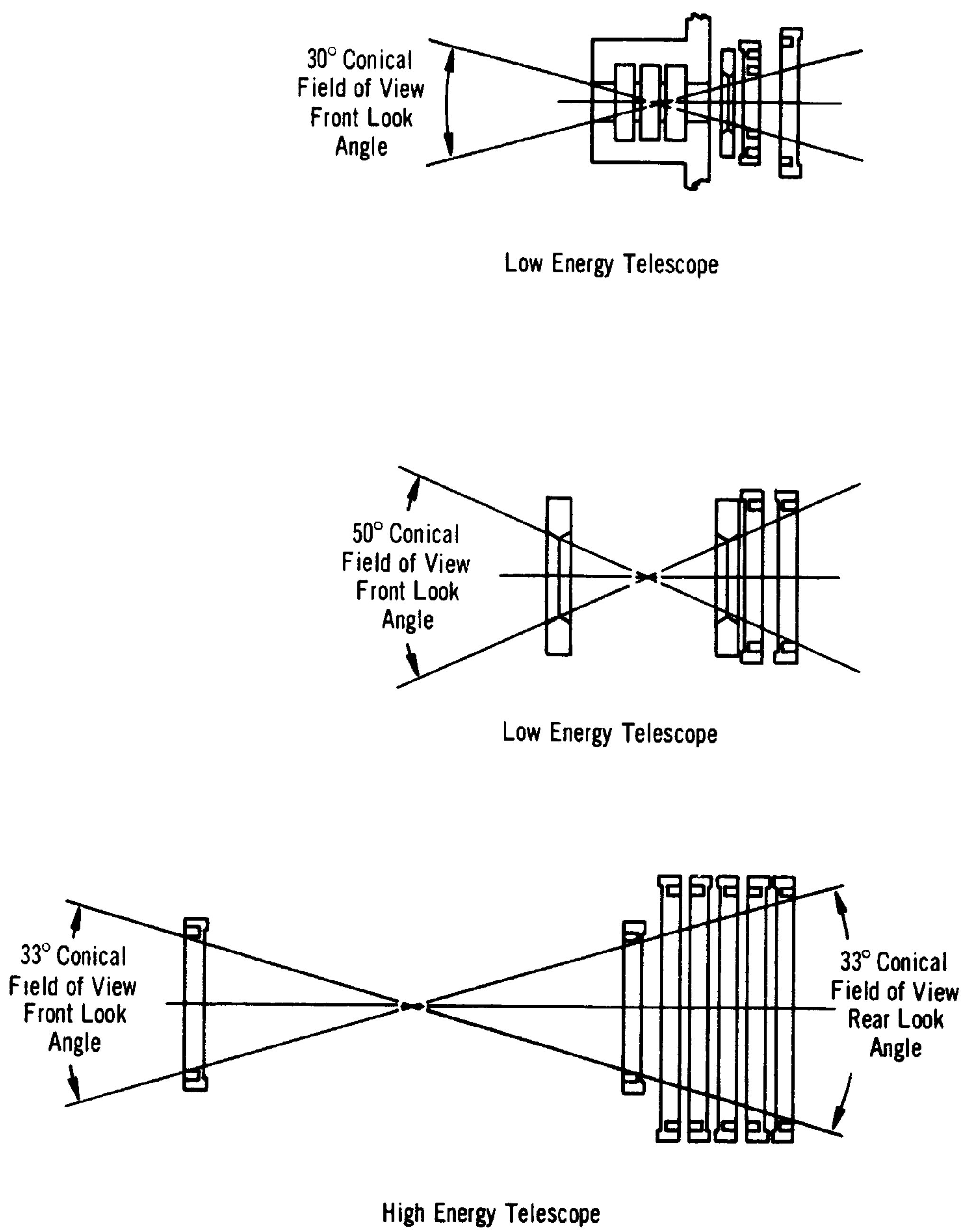


FIGURE 16.—A set of low-energy telescopes and a high-energy telescope will be used for cosmic-ray research.

TABLE 2.—*Cosmic-Ray Telescope Objectives*

Particle components:	*Energy Range*
Galactic cosmic-ray protons	4.5–800 MeV
Solar protons	0.05–800 MeV
Galactic cosmic-ray helium	4.5–600 MeV/nucleon
Solar helium	1.0–600 MeV/nucleon
^{3}He/^{4}He, D/H	4.5–50 MeV/nucleon
Galactic and solar electrons	0.050–5.0 MeV
Li, Be, B, C, N, O, F, Ne, and their isotopic composition	6 MeV/nuc–200 MeV/nucleon
Integral flux	> 800 MeV

helium, and electrons. From such studies and similar surveys elsewhere, more may be learned about cavities that planets may cause in solar radiation, what happens at the boundaries of such cavities, and estimates improved of the density of cosmic rays out in interstellar space.

RADIATION BELT OBSERVATIONS

The belts of charged particles near the Earth are trapped by its magnetic field from radiation in the interplanetary medium. Much has been learned about them since they were discovered slightly more than a decade ago, but there are still questions about what happens in those belts. It is widely believed, for example, that diffusion processes accelerate the energetic particles in those belts—but little progress has been made in identifying the mechanisms involved because the researchers cannot vary the parameters.

Convincing evidence has been obtained from radio telescopes that there are also radiation belts around Jupiter. It is the solar system's electrically noisiest planet. The parameters there are clearly different from those near the Earth. Measurements of the solar wind and cosmic radiation will help scientists determine the differences. A third pair of Pioneer F and G experiments will further augment information about the Jovian belts.

Geiger-Tube Telescope

Prof. J. A. Van Allen's name was given to the Earth's radiation belts for his role in discovering them,[9] and he and his graduate students at the University of Iowa will conduct one of the studies of Jovian trapped radiation. They will use seven Geiger-Mueller

[9] Asimov, Isaac: *Twentieth Century Discoveries* (Doubleday & Co., 1960), p. 155.

tubes to survey the intensities, energy spectra, and angular distributions of electrons and protons along the trail that the Pioneers will open through the magnetosphere of Jupiter.

These tubes are small cylinders containing gas that generates electrical signals from charged particles. Three of them will be alined linearly, as shown in figure 17, and function as a multipurpose

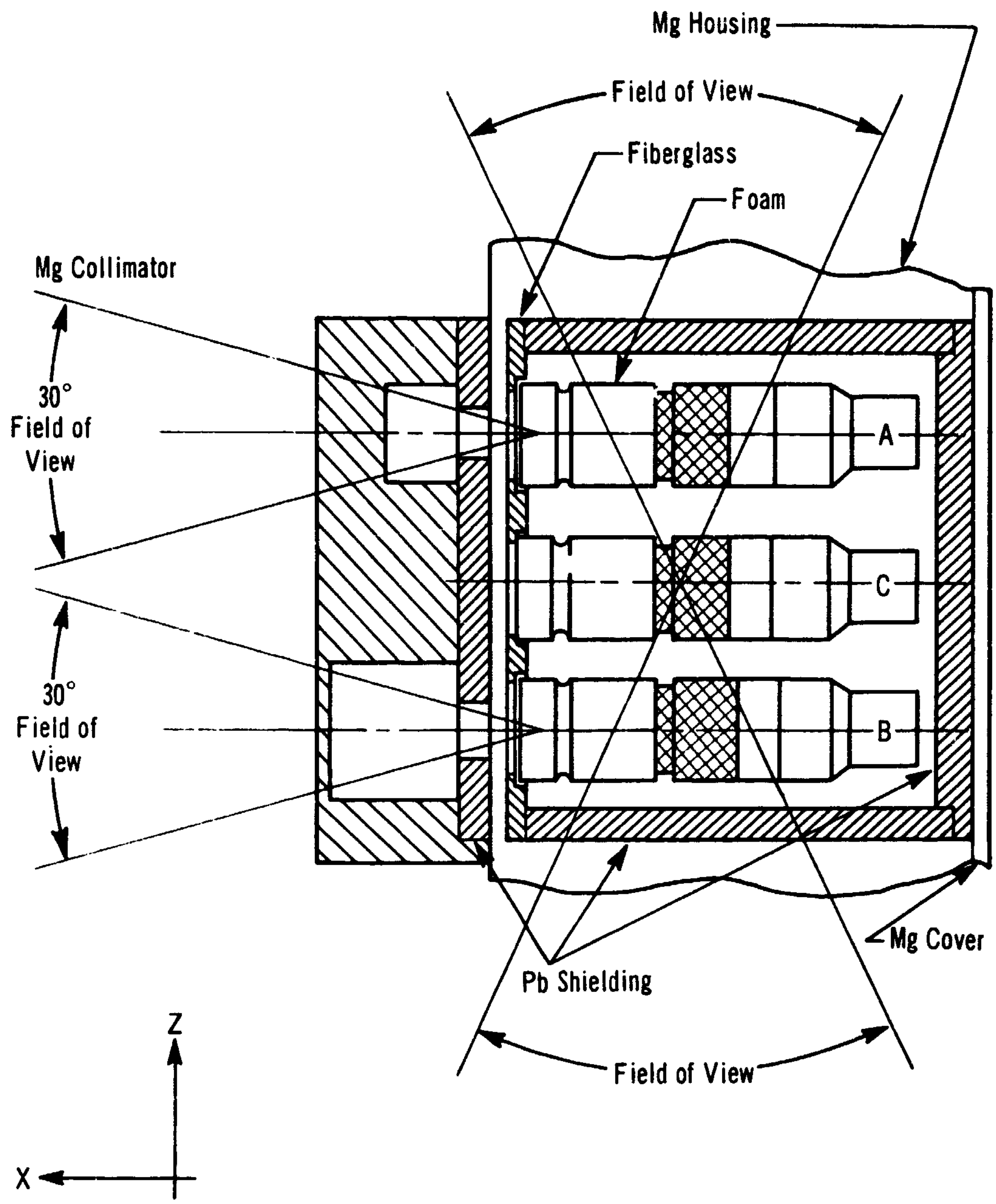


FIGURE 17.—The Geiger-tube telescope will contain three parallel cylinders and will rotate with the spacecraft. Fields of view of tubes A and B will be in an equatorial strip along the vehicle's path. Tube C will count particles that penetrate the telescope's shielding and give investigators the background rate needed to correct data from A and B.

telescope. Three others will be in a triangular array, spaced so that no straight line can pass through all three, and be used to measure the number of showers (multiple-particle events) occurring. This combination of a telescope and a shower-detecting array will enable them to compare primary events in the Jovian radiation belt with secondary events.

A seventh Geiger tube will be a low-energy electron detector with which a geometric factor can be added to the information from the other tubes. The investigators expect their findings with this apparatus to be enlightening regarding the shock front and the tail of the Jovian magnetosphere. Protons having energies above 50 MeV and electrons with energies between 2 and 50 MeV will be counted in the Van Allen experiment.

Trapped Radiation Telescope

Dr. R. W. Fillius and Prof. C. E. McIlwain of the University of California at San Diego will be studying charged particles trapped around Jupiter with a different kind of telescope at the same time as Prof. Van Allen. Their apparatus has been designed to cover a broader range of energies—2, 5, and 11 MeV for electrons and above 450 MeV for protons—than the spectra to which the Geiger tubes will be responsive.

This apparatus aboard the Pioneers will include several kinds of detectors (fig. 18). One will be an unfocused Cerenkov counter that detects particles by the light emitted in a particular direction as they dart through space. The others will be an electron scintillator, a proton scintillator, a detector for minimum ionizing particles, and one for observing electron scatter. These five "eyes," installed as shown in the figure, will make it possible for the investigators to obtain basic indications of several of the fundamental features of Jupiter's radiation belts—including the separation of species, rough descriptions of angular distributions and energy spectra, and measurements of absolute intensities over an extended range.

Currently favored theories about Jupiter have been based largely on the findings of the radio astronomers. Jupiter is known to be the source of three principal types of radiofrequency noise—decametric, decimetric, and thermal—and the Pioneer F and G studies of its radiation belts are expected to make better interpretations of those emissions possible. This will help astronomers decide between conflicting hypotheses about such puzzling matter as Jupiter's structure. From the two experiments just described, electrical engineers will also learn more about a radiation environment that may affect

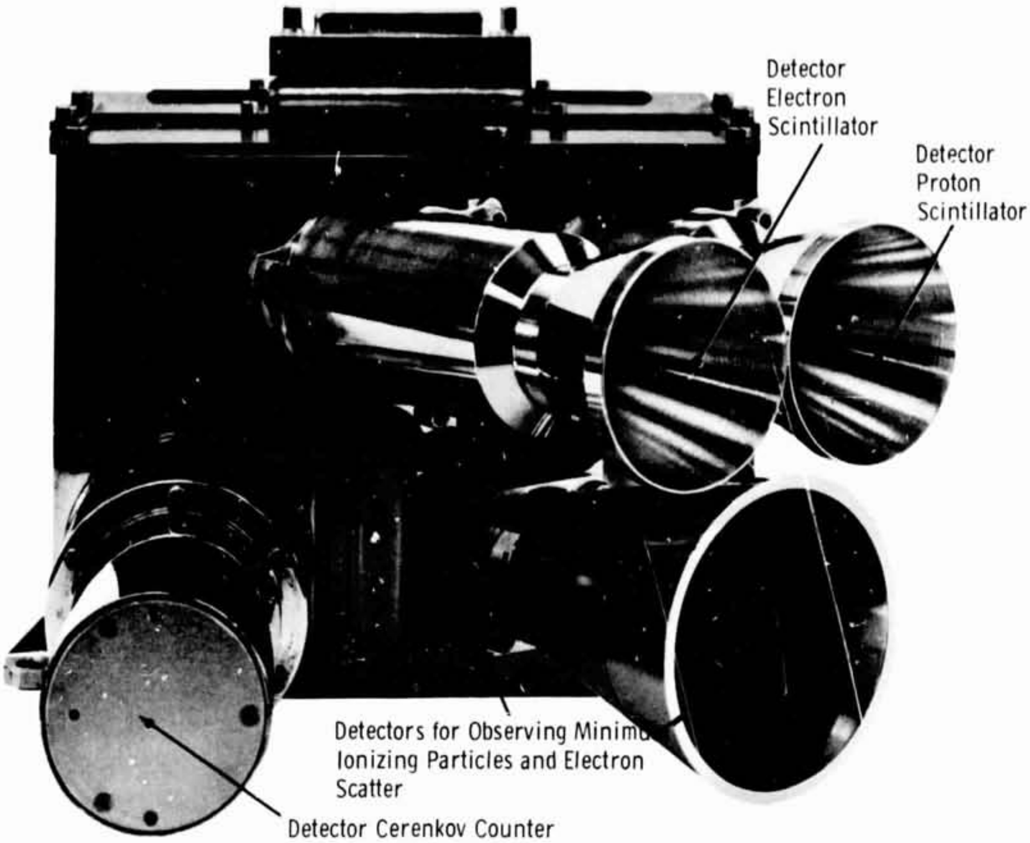


FIGURE 18.—The trapped radiation detector will be an array of five detectors covering energy ranges between 0.1 and 10 MeV for electrons, and between 0.05 and 350 MeV for protons. Aperture for observing minimum ionizing particles is in the base of the one for observing electron scatter.

the performance of future spacecraft sent to the outer realms of the solar system.

THE JOVIAN ATMOSPHERE

From observatories on the Earth the turbulent atmosphere of Jupiter is as puzzling now as the Earth's atmosphere was to everyone until a few centuries ago. The last three instruments listed in table 1 will be used to learn more about it from its light and warmth. Scientists can draw numerous conclusions from ultraviolet light, thermal energy, and the way that clouds reflect sunlight. The ultraviolet photometer, the infrared radiometer, and the imaging photopolarimeter, of course, will also be employed during the many months before the spacecraft draw close to Jupiter. Then, in a few days while the Pioneers are flying by their target, astronomers may obtain data from those instruments that will help them explain why Jupiter and the Earth are so different.

Ultraviolet Photometer

This 1.4-lb device, the lightest scientific apparatus aboard the spacecraft, will be used by the physics faculty of the University of Southern California at Los Angeles. Both Dr. D. L. Judge, the principal investigator, and Dr. Robert W. Carlson, his coinvestigator, have participated in many previous studies of ultraviolet light with sounding rockets and satellites.

The sensor used in this experiment will have a lithium fluoride eye 1.5 inches wide that will respond to radiation in the extreme ultraviolet range, between 200 and 800 angstroms. Although the photometer will only observe evidence of helium in this wavelength, the findings will indicate interactions between charged particles and neutral hydrogen.

Somewhere the supersonic solar wind subsides to a subsonic breeze. Estimates of the distance from the Sun that this happens now range from 2 to 100 AU. While the two Pioneers are going from 2 to 5 AU, the ultraviolet photometer will be used in a search for the inner boundary of the transition zone.

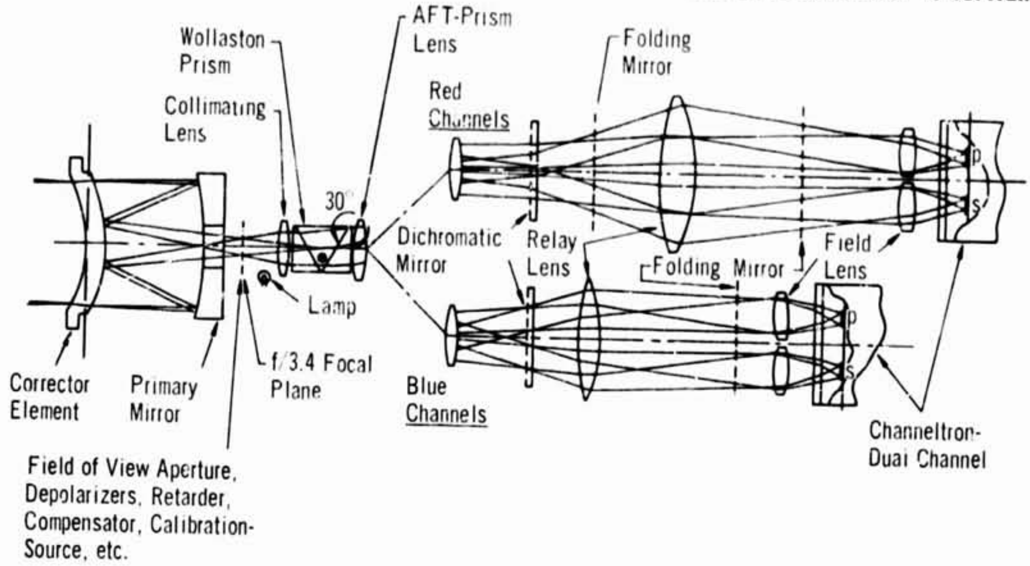
During the encounters with Jupiter, the photometer will be used to look for evidence of an auroral oval in the radiation on the day side of the planet, to find the ratio of helium to hydrogen in the Jovian atmosphere, and to take the temperature of the outer portion of that atmosphere.

Infrared Radiometer

This instrument will be flown to Jupiter for some of the same California Institute of Technology scientists who were responsible for infrared observations of Mars: Dr. Guido Munch, a noted astrophysicist from Mexico, Dr. Gerry Neugebauer, and their colleagues.[10] In their radiometer, a 3-inch Cassegrain telescope will illuminate thermopiles to measure the irradiance in two ranges of thermal wavelengths, between 14 and 25 microns and between 19 and 56 microns. It is a comparatively simple device of the same type that was placed aboard two Mars Mariners, but measurements made with it from the Pioneers will be more accurate and have better spatial resolution than any that can be made from the Earth.

Data returned from it can help to dissipate many mysteries about Jupiter, and theories based on observations of the shadows that Jupiter's satellites cast on the planet's rapidly rotating atmosphere may be substantiated, clarified, or discredited. The investi-

[10] *Mariner Mars 1969: A Preliminary Report*, NASA SP-225, p. 143.



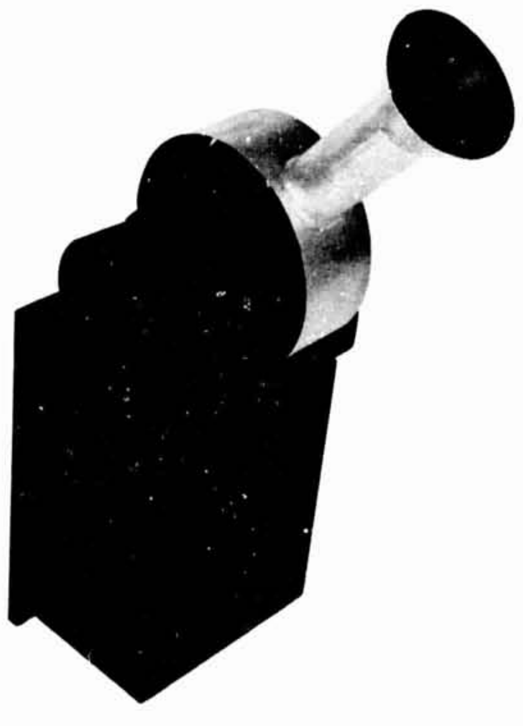


FIGURE 19.—The imaging photopolarimeter will be the second heaviest scientific instrument carried on the Pioneers. The model shows how it will appear and the diagram how it will work. Images from both the red and the blue channels will be transmitted to Earth for construction of pictures.

gators expect, for example, to find out definitely whether Jupiter is or is not radiating a significant amount of internal energy in addition to reflecting solar energy. Many scientists believe that it is, but the evidence available has not been conclusive.

The infrared photometer will be used to search for hot spots in the planet's outermost atmosphere and to map the temperature distribution. This may help to explain its great Red Spot. Whether Jupiter does or does not have a polar cap, and the temperature of the dark side, may be learned. Details of the general composition of the planet's surface, including the overall hydrogen-to-helium ratio, also may be garnered from analyses of the thermal data and relating it to other findings.

Imaging Photopolarimeter

The information from all of the 11 sensing devices aboard the next two Pioneers will be transmitted to the Earth digitally. Virtually all of it is expected to be significant to scientists, but only the imaging photopolarimeter will produce data intended to be highly pictorial. Prof. Tom Gehrels of the University of Arizona's Lunar and Planetary Laboratory and six colleagues will direct the use of this 9.1-lb apparatus, in which an imaging device is combined with a polarimeter and a photometer.

For their research, a pointable 1-inch aperture telescope (fig. 19) will protrude from the side of the spacecraft's instrument housing. It will sweep out a cone while the spacecraft spins, and data will be obtained in the form of scans along the viewing cone. The light that the telescope collects will be analyzed for color and polarization at the focal point, and filtered before it reaches photoelectric detectors. Those detectors will provide digital data for transmission to the Earth that can be corrected to reduce distortions of the spin-scan process, and used to construct images of Jupiter.

Before the encounter with the big planet, the imaging photopolarimeter will be utilized to study zodiacal light as part of efforts to assess the quantity and distribution of particulate matter in space and identify the nature of the particles. Periodic maps will be obtained of the brightness and polarity of light outside the spacecraft over a wide range of scattering angles during the long flight.

When the Pioneers approach Jupiter, this telescope may be pointed at one or more of that planet's large satellites to search for evidence of an atmosphere. Its findings then may help to reduce bewilderment about the origins and structures of Jupiter's moons. The solar system's dominating planet will be scanned, too, of course, for photometric and photopolarization studies.

The investigators expect to obtain two-color images with a resolution of 200 kilometers, in both the red and blue spectral bands, of Jupiter's surface (fig. 20). Those are likely to be the best pictures ever taken of a planet beyond the asteroid belt.

Thousands of amateur astronomers, science teachers, and journalists will be intensely interested in seeing those pictures, and professional astronomers will be awaiting them even more eagerly. With such pictures in hand, features of the planet that scientists have observed, studied intensely, and wondered about for centuries may be seen more clearly.

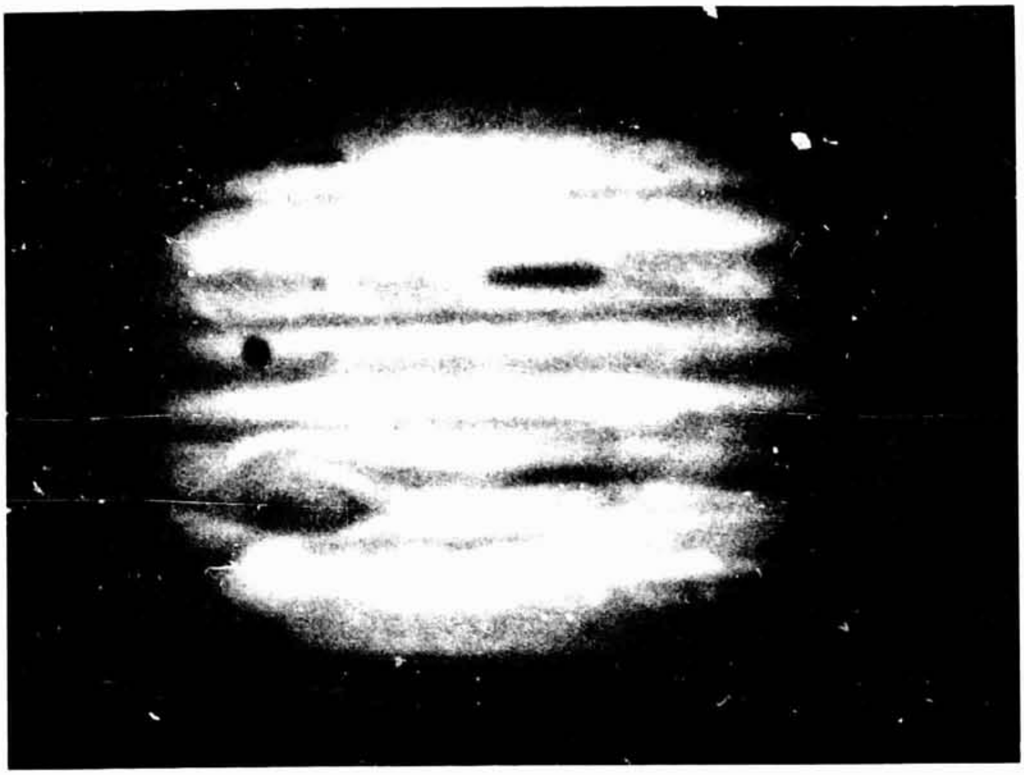
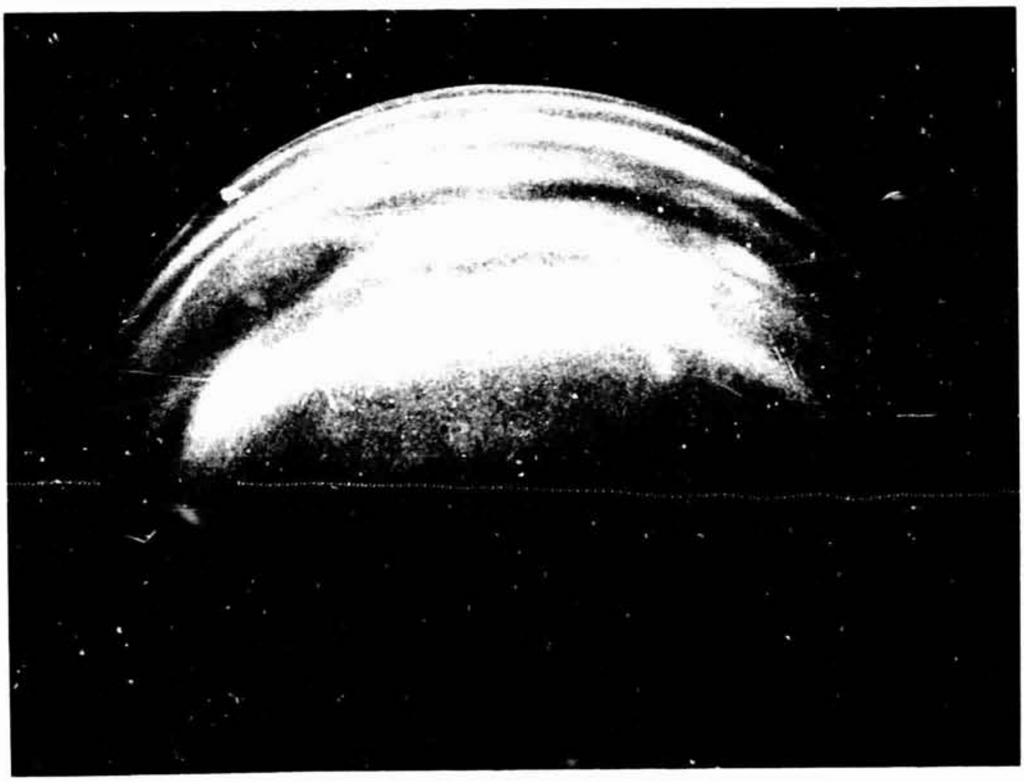


FIGURE 20.—The photo above shows how Jupiter looks through a 61-inch telescope on the Earth. The one below is a simulation of the way it may be seen if Pioneer G is placed in one possible orbit to obtain images of the Great Red Spot, shadows of satellites, and other features of the colossal planet.



III

SPACECRAFT AND SUPPORT

Pioneers F and G will be new versions of a probe that NASA has used to explore the solar system for 12 years. Three early Pioneers did not reach the orbits that they were expected to, but the nine listed in table 3 have added immensely to scientific information about the Earth's surroundings and still were transmitting data in 1971. By then Pioneer 6, which was launched in 1965, and Pioneer 8, launched 2 years later, were at distant points 100 million miles apart. Their alinement then made it possible to measure the solar wind's density between them more accurately than this ever could be done previously.

For journeys to Jupiter the spacecraft and some of the equipment have been modified in significant ways (fig. 21). The scientific instruments, of course, also have been especially designed to meet the rigors that are foreseen, but no major alterations in launching facilities and communications networks developed for other flights will be necessary.

TABLE 3.—*Successful Predecessors of Spacecraft*

Name	Launched	Achievements
Pioneer 1	1958	Found extent of Earth's radiation bands.
Pioneer 2	1958	Improved data on flux and energy levels of particles.
Pioneer 3	1958	Discovered second radiation belt near Earth.
Pioneer 4	1959	Extended measurements to within 37 300 miles of the Moon.
Pioneer 5	1960	Obtained solar flare and wind data.
Pioneer 6	1965	Continued to report data after traveling 3.3 billion miles.
Pioneer 7	1966	Reported data during solar cycle from widely separated points within 1.125 AU of the Sun.
Pioneer 8	1967	Reported data during solar cycle from widely separated points within 1.09 AU of the Sun.
Pioneer 9	1968	First spacecraft to transmit at 3 frequencies through the solar corona to measure the electron concentration.

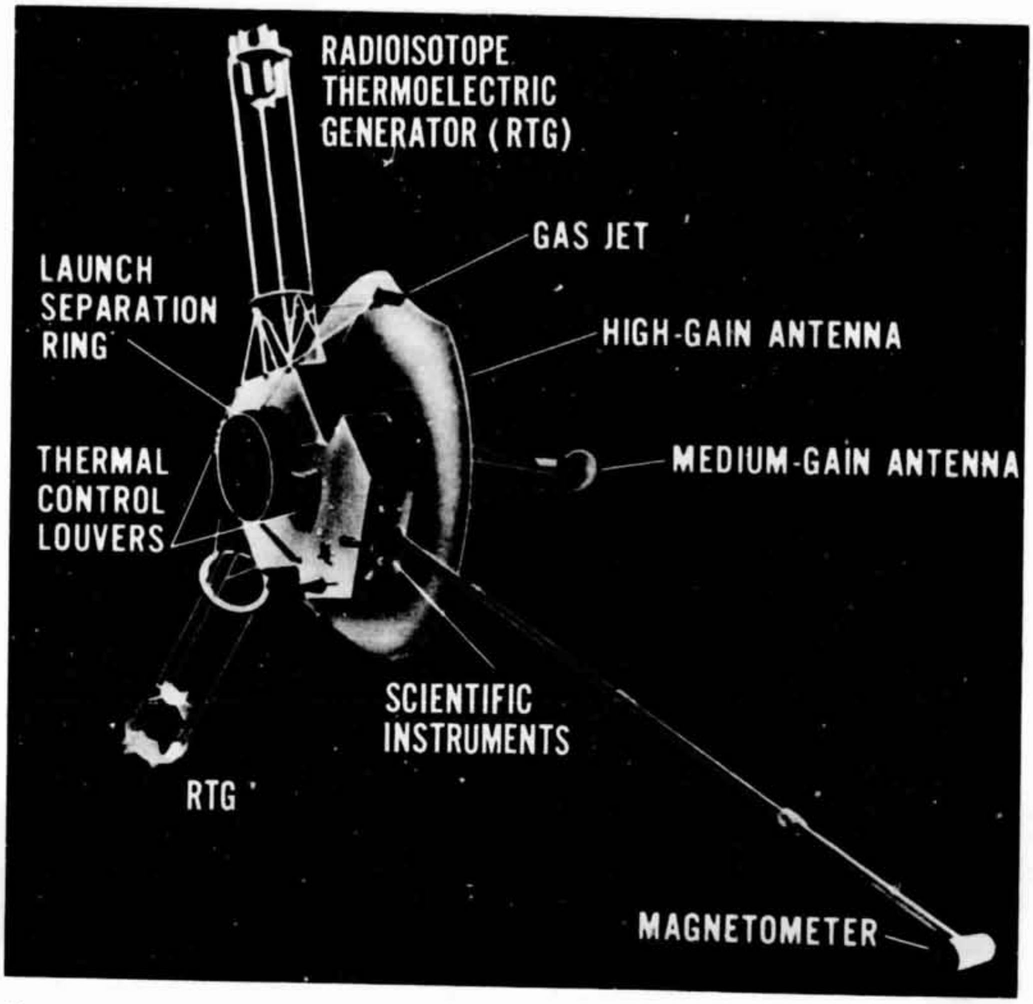


FIGURE 21.—Here you see the placement of the hexagonal hub and compartment for experimenters' apparatus behind the high-gain antenna. Note how the magnetometer will be isolated from the sources of electric power.

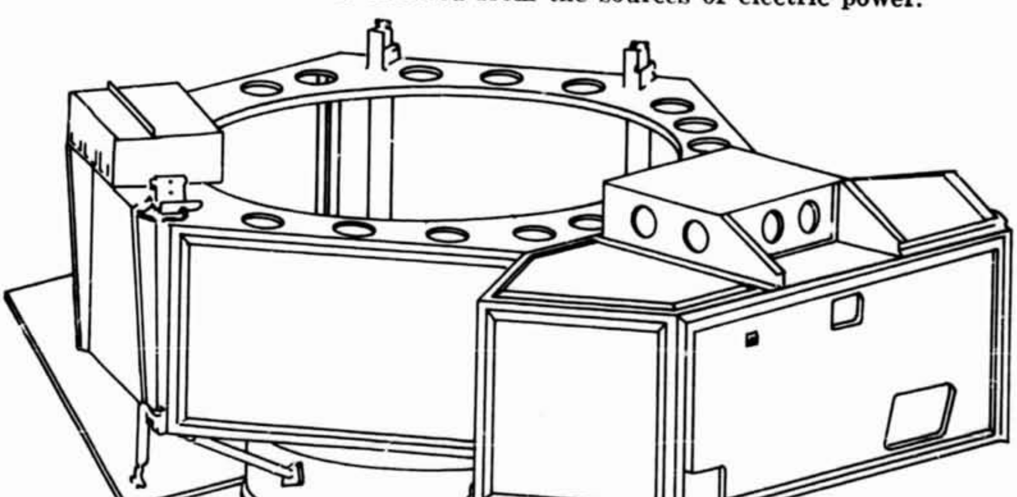


FIGURE 22.—The basic structural unit is a hexagon in which operational equipment will be housed between the separation ring and the antenna dish.

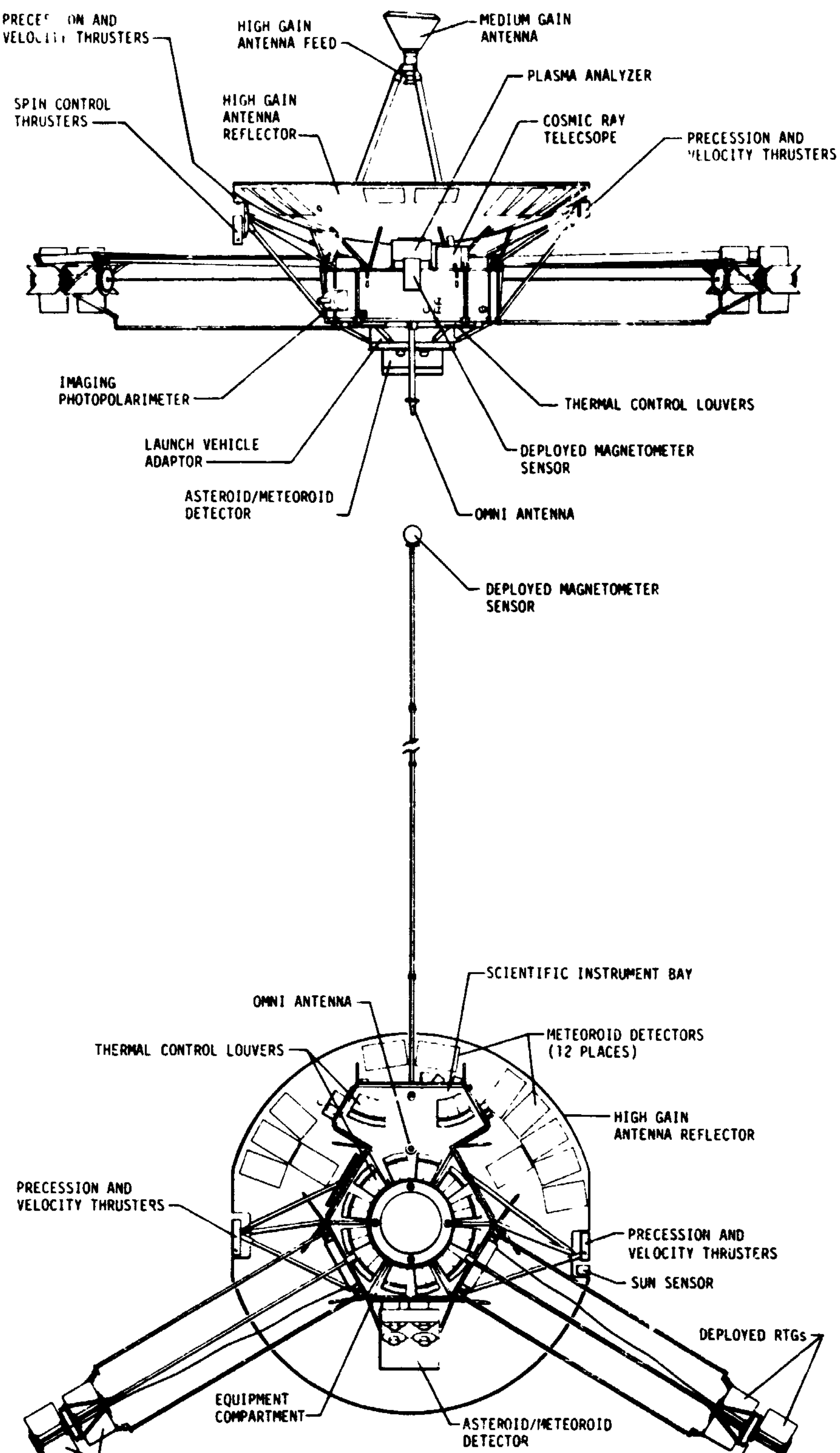


FIGURE 23.—Placement of many of the components of Pioneer F and G mentioned in this monograph can be seen here. The instruments labeled are described in part II of this monograph.

The launching requirements, the range of environments in which Pioneers F and G must operate, and the exacting demands for 11 different kinds of accurate scientific measurements, have imposed serious constraints on the designers of these vehicles. Hence the mission will be a test of the state of numerous engineering arts. There are novel as well as familiar features throughout the spacecraft—in its structure, in its electrical power system, and in its communication apparatus. New facilities for receiving and processing data from spacecraft will also be available for initial use in such a program.

STRUCTURAL CHALLENGES

Neither Pioneer F nor G should weigh more than 560 lb. Each must be stowed for launching within a cylindrical envelope only 9 feet in diameter and 8 feet long, but deployable appurtenances will more than double the vehicle's width throughout most of the mission. Radioisotopes will provide the heat for the electrical generators on board the spacecraft, and also will be used to warm the fuel for thrustors required to adjust the vehicle's attitude and velocity from time to time.

The basic structural component of the vehicle will be a hexagonal hub (figs. 22 and 23). It will have an aluminum sandwich floor, an aluminum frame, and sides made of aluminum honeycomb covered by an insulating blanket of many layers of aluminized Mylar. During the launching it will rest on a separation ring and support all other parts of the spacecraft. Above it there will be a 9-foot-wide dish to serve as the reflector for a high-gain antenna. Communication and other operational equipment will be in the hexagonal body.

Scientific instruments will be isolated from such equipment in a separate compartment on one side of the hexagon. Within both of these two main compartments, the range of temperature must be kept very small relative to that of the environment outside.

Magnetic Cleanliness

Apertures in the sides of the compartment containing the scientific instruments will admit light to the sensing systems, and a 15.8-foot-long mast will protrude out from that compartment for magnetic-field measurements. Any electrical current flowing within a spacecraft can produce a magnetic field sufficient to distort measurements of weak interplanetary fields.[11] The sensor for the effort to

[11] Naugle, John E.: *Unmanned Space Flight* (Holt, Rinehart & Winston, Inc., 1965), p. 37.

measure those fields from Pioneers F and G will therefore be placed as far as possible from all such currents. The designers of the vehicles also have striven to make them as magnetically clean as possible, not only by careful testing and selection of materials for all components but also by the placement of all necessary electrical apparatus.

The electrical generators will be on the outer ends of two 5.7-foot-long trusses that will be deployed from the body of the spacecraft after it has been separated from the launch vehicle. At the same time the mast for the helium vector magnetometer's sensor will be deployed in a different direction. It will be pointed away from the two trusses that support the generators at a 120° angle to each of them. Consequently the magnetic fields from sources within and attached to the spacecraft are expected to be less than 0.1 gamma at the point where the natural interplanetary fields are observed, thus facilitating measurements of very weak portions of those fields.

Thermal Control

A second major problem for the designers was how to maintain reasonable temperatures within the body of the spacecraft throughout all phases of the Jupiter journey. When the spaccraft is launched, it will be warmed both by the rocket engines and the radioisotopes stored within its shroud. The flight trajectory will take it farther and farther from the Sun, month after month, and subject it to greater coldness than any of NASA's previous probes of the solar system. Yet the ambient temperature must not prevent operation of its control and communication systems or the performance of scientific experiments.

Temperatures in the immediate vicinity of the scientists' instruments will be kept between 0° and 90° F. This will be done partly by using special surface finishes, boots, wraps, and multilayered blankets made of Mylar and Kapton. The spacecraft also will have louvers facing away from the Sun that will be opened and closed by the differential expansion of bimetallic springs.

Attitude Control

When the spacecraft leaves the final stage of the launching vehicle behind, it will be spinning rapidly. Before the structures to support its electric generators and the magnetometer sensor are deployed, the spin rate will have to be reduced from about 60 to about 30 rpm. Those appurtenances will then lower that rate to 4 or 5 rpm.

Further changes in the spin rate and in the spacecraft's attitude or velocity will be needed to keep it on course, to point scientific sensors at the desired targets, and to maintain communication between the Pioneers and the Earth. Those adjustments will be made by clusters of small thrustors. There will be two of them, on opposite sides of the spacecraft near its outer perimeter. One nozzle in each cluster will face forward, another to the rear, and a third nozzle will be alined tangentially to the spin axis of the spacecraft. Pulses will be released from them to control the precession and velocity of the vehicle.

Gas for expansion through the thrustor nozzles will be produced by the decomposition of hydrazine in a catalyst bed. The hydrazine will be in a spherical, pressurized bladder in the equipment compartment. Hydrazine freezes at about 35° F, and both electrical and small radioisotope heaters will be used to keep it liquid and ready for use.

The timing of the pulses from the thrustor nozzles will be determined by signals from the Sun or star sensors and ground calculations. The Pioneers will be able to home on radio signals from the Earth, to heed commands from the Earth, and to store such commands for execution later, in the sequence and at the times that calculations indicate are necessary.

ELECTRICAL REQUIREMENTS

To provide sufficient, reliable, electrical power for a spacecraft headed for Jupiter, the electrical engineers faced problems as unprecedented as those of the mechanical engineers responsible for the structure of the vehicle. Batteries would be exhausted if not recharged. If solar cells were used, as on the Mariner Mars missions, enormous numbers of them would be required to generate enough power 5 AU from the Sun. Radioisotope thermoelectric generators (RTG's) were chosen, therefore, for Pioneers F and G. Isotopes release much more energy per pound than chemical fuels. The U.S. Navy first tried this new kind of generator on navigation satellites. NASA has since used it on its Nimbus weather satellite and placed RTG's on the Moon, but this will be the first use of an RTG on an interplanetary spacecraft.

The unit chosen for the next two Pioneers will be an advanced SNAP-19 (SNAP is an acronym for System Nuclear Auxiliary Power) that was developed jointly by the Atomic Energy Commission and NASA (fig. 24). Pioneers F and G will each have four of these units. Each unit will be enclosed in a small cylinder and weigh about 30 lb. Two of the cylinders will be mounted on the outer end of each of the two booms that are to be deployed from the hexagonal body of the vehicle.

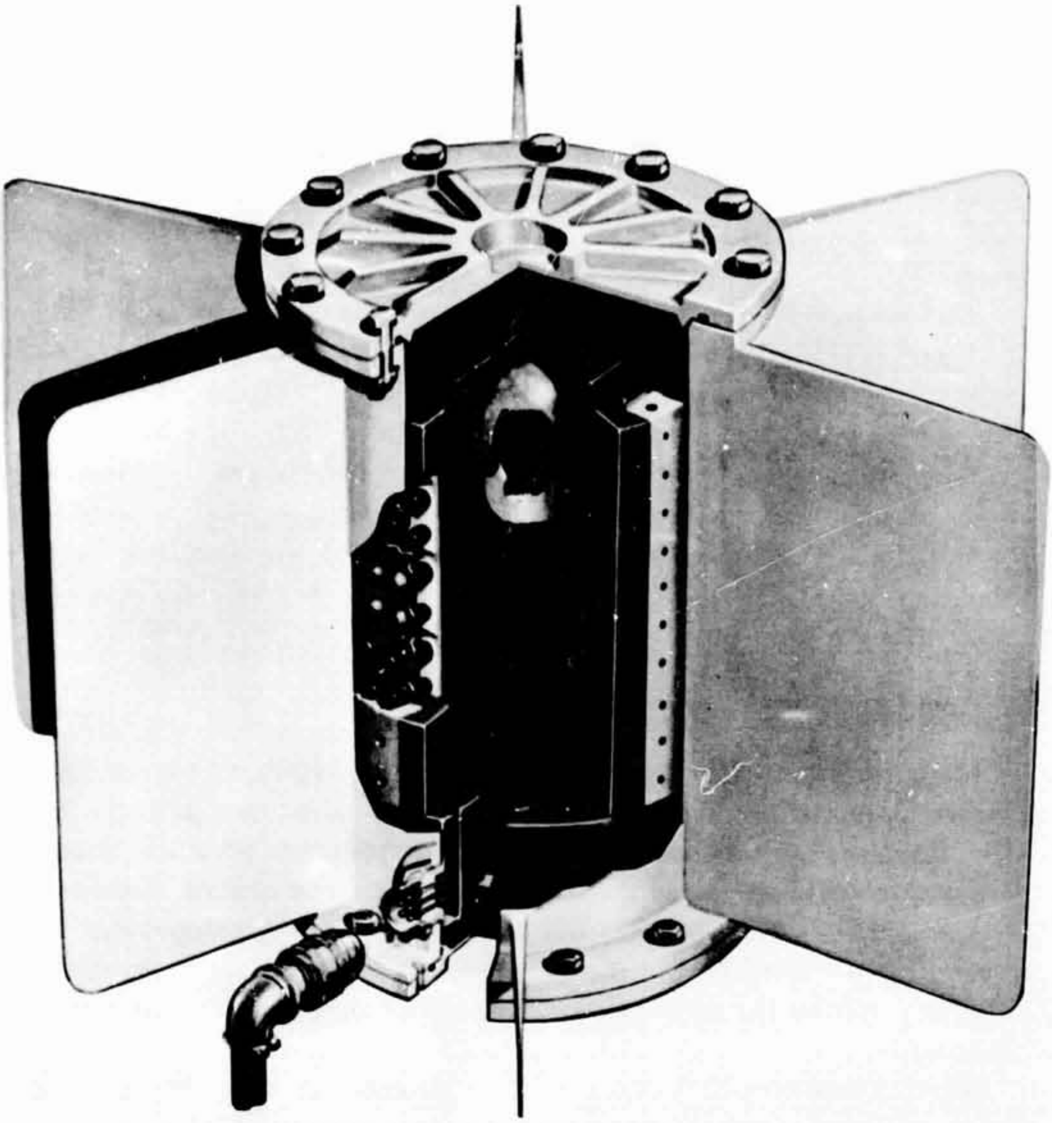


FIGURE 24.—The radioisotope power generators, provided by the Atomic Energy Commission through Sandia Corp. and Teledyne Corp.'s Isotopes Division, will be a modified version of a generator tested on a Nimbus weather satellite.

In this type of RTG, plutonium-238 produces heat as it decays. The heat is converted into electricity by thermocouples (the first devices ever invented to produce electric currents from heat without the help of moving parts). These thermocouples will be made of semiconductor materials. The *n*-elements will be lead telluride, and the *p*-elements will be an alloy of tellurium, silver, germanium, and antimony. There will be 90 such thermocouples in six modules warmed by the plutonium-238 in the core of each generator.

As the plutonium decays, it will produce less heat and the generators will deliver less power. The RTG's chosen for the Pioneers will each be capable of providing nearly 40 watts of power during the early part of the mission and about 30 watts of power 5 years later. Three such generators should suffice to meet the requirements for experiments and communication at the time of the Pioneer encounters with Jupiter, but each spacecraft will have four of the units to reduce the possibility of a power shortage at a crucial moment.

The output from each RTG will go to a separate inverter, which will be paralleled with the other three inverters to form an alternating current (ac) bus. Most of the ac power will be rectified and filtered to supply a main 28-volt dc bus, from which the instruments will receive power. Most of the other demands aboard the spacecraft will be met from a central transformer rectifier that will receive power from the ac bus and deliver various dc voltages. A battery will be recharged automatically when enough power is available, and used to meet any temporary overloads.

THE COMMUNICATION SYSTEM

Men have never controlled and received readings from scientific instruments so far away as the next two Pioneers will go from the Earth. Despite the long distances, streams of data must be transmitted from and to the Earth throughout much of the Jupiter mission. This will be possible thanks to such developments as a traveling-wave-tube amplifier that weighs only 3.85 lb and takes up only 150 cu in. of space, yet has an rf output of 8 watts in the S-band.[12]

Each Pioneer will have a high-gain antenna (fig. 25) for communications at maximum data rates and extreme distances, and a pair of medium- and low-gain antennas for broad-angle communications at intermediate and close ranges. The parabolic reflector for the high-gain antenna will be an aluminum honeycomb sandwich, as wide as can be accommodated within the shroud of the launch vehicle. The medium- and low-gain system will have two elements, a horn facing forward and a spiral pointed to the rear. Each antenna will always be connected to a receiver in the spacecraft, and the receivers will be interchangeable when commanded from the ground or automatically after a certain period of inactivity.

By 1973, when the Deep Space Network of ground stations will be needed to communicate with these Pioneers, it will have three 210-foot-diameter antennas, spaced equidistantly around the world, in addition to a network of 85-foot antennas. Both sizes of antennas

[12] *Communications Designer's Digest*, Nov.-Dec. 1970, pp. 26–27.

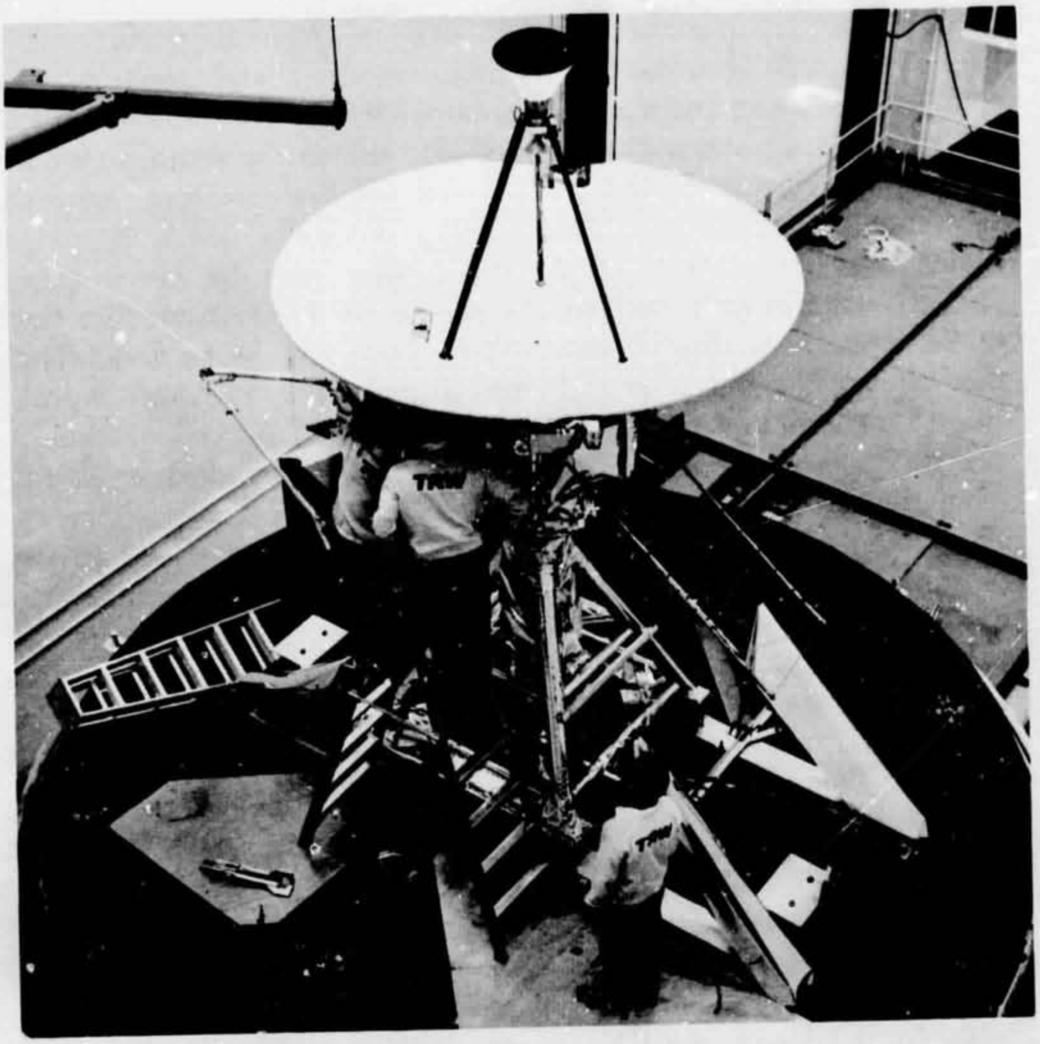


FIGURE 25.—The high-gain antenna is over the heads of the engineers whom you see here checking out the Pioneer spacecraft's equipment during the assembly of the vehicle. The big dish will be pointed toward the Earth during the journey to Jupiter.

can be used to transmit orders to the Pioneers and receive data from them, even at the range of Jupiter. The power required will be much lower and the rate at which data are transmitted can be much higher, however, when the 210-foot antennas and the high-gain antenna of the spacecraft are used than when the other antennas must be employed. Up to 1024 bits of information per second can be transmitted from the vehicle to the 210-foot ground antennas while it is in the vicinity of Jupiter, but only 64 bits per second to the 85-foot antennas.

The spacecraft will be capable of receiving and acting on 255 discrete commands from the Earth. These will be sent by modulation of the S-band carrier signal, and each command will consist of

22 bits. Only 8 of those bits will contain command information; the others will be used for routing, decoding, and verifying the messages. Timing and operational orders will be transmitted both to the various subsystems of the spacecraft and to the scientific instruments. No command will be executed until it has been correctly routed and verified.

Readings from the scientific instruments may be either transmitted instantly or stored on the spacecraft for transmission later under more favorable circumstances. Data can be read out from the system's memory at any of eight different bit rates for transmission to the Earth.

Data from the scientific experiments will be handled separately from the engineering data, but both types will be received on the Earth in a single stream. Separate formats will be used to distinguish the types of data transmitted, and redundancy will be built into most parts of the digital telemetry unit. Special formats will enable investigators to sample data from certain instruments at a high rate by reducing the rate of transmission of other data. This feature will be especially helpful to the scientists during the brief time that the spacecraft will be quite close to Jupiter.

ORGANIZATION AND MANAGEMENT

In planning this mission, NASA has drawn heavily on experience, techniques, and skills acquired in lunar exploration, in seven previous planetary missions, and in its efforts to place a Mariner in orbit around Mars in 1971. In numerous respects, as indicated in table 4, the Pioneer F/G project is a much more ambitious, challenging, and complex undertaking than orbiting Mars.

TABLE 4.—*Mission Comparisons*

	Mariner 71	Pioneer F/G
Flight time to accomplish objectives	9 months	20 months
Communication distance	250×10^6 km	700×10^6 km
Solar intensity (relative to Earth) at encounter	0.4	0.04
Launch energy required	9 km^2/sec^2	90 km^2/sec^2
Onboard apparatus for scientific experiments	4	11
Maximum telemetry bit rate at encounter	16 000 bits/sec	1024 bits/sec
Total information transmitted during nominal mission	50×10^9	78×10^9

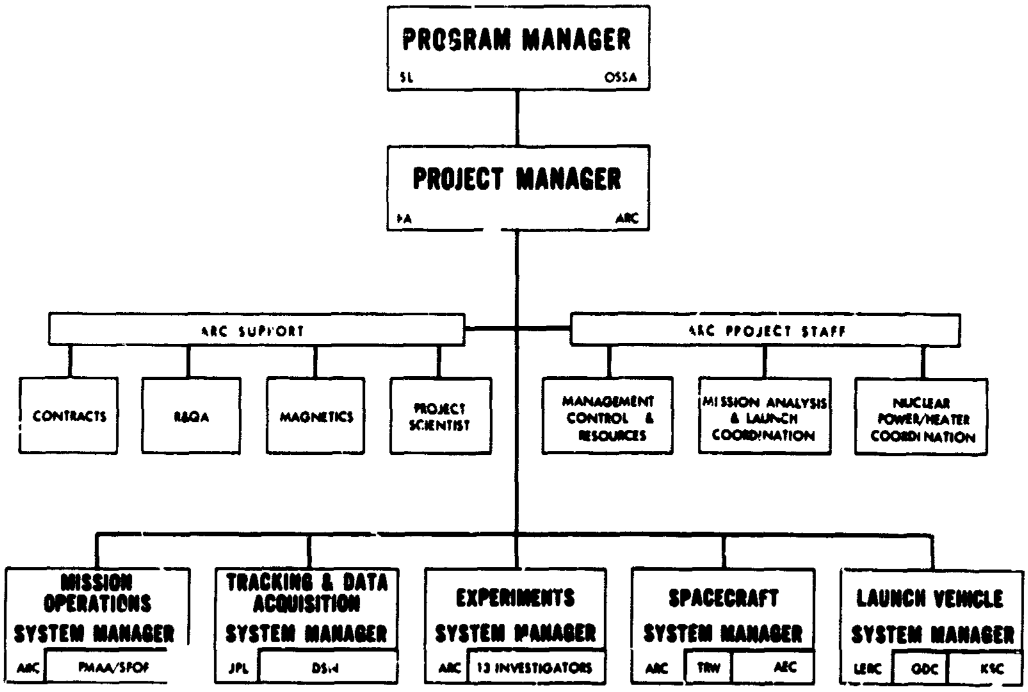


FIGURE 26.—The basic organization of the Pioneer project shows the five key systems at the bottom here. They correspond to those for the Mariner Mars 1971 project.

Responsibility for the management of the Pioneer F/G project has been entrusted to the Ames Research Center by the NASA Office of Space Science and Applications. (Figure 26 shows the basic organization.) Both the management and the implementing organizations have been and will continue to be guided and aided by many of the Nation's most highly regarded scientists, engineers, and institutions. Some of the participating organizations are listed in table 5.

LAUNCHING AND CONTROL

The Atlas-Centaur combination that NASA has used for several years will provide the first two stages of propulsion when Pioneers F and G leave Pad 36A at the Cape Kennedy Air Force Station. The Atlas first stage has two Rocketdyne booster engines. The Centaur second stage has two Pratt & Whitney engines powered by liquid hydrogen and liquid oxygen. The third and final stage of propulsion will be provided by a Thiokol solid-propellant motor. This will be its first operational use with the Atlas-Centaur combination.

The countdowns and launchings will be controlled from the Kennedy Space Center. Air Force and Manned Space Flight Network facilities will be used for the downrange tracking. The launch azimuth will be between 90° and 110° east of north, and the powered

TABLE 5. *-Project Participants*

Elements	Management organizations	Implementing organizations
Instruments:	Ames/Pioneer Project Office	
Meteoroid detector		Langley Research Center
Asteroid/meteoroid detector		General Electric Co.
Plasma analyzer		Time Zero Corp.
Helium vector magnetometer		Jet Propulsion Laboratory.
Charged particle detectors		University of Chicago.
Cosmic-ray telescope		Goddard Space Flight Center.
Geiger-tube telescope		University of Iowa.
Trapped radiation telescope		University of California at San Diego.
Ultraviolet photometer		University of Southern California.
Infrared radiometer		Santa Barbara Research Center.
Imaging photopolarimeter		Santa Barbara Research Center.
Spacecraft:		
RTG's	AEC Space Nuclear Systems	Teledyne Isotopes, Mound Laboratories Division of Monsanto.
All other components	Ames/Pioneer Project Office	TRW Systems Group, TRW, Inc.
Launch vehicle	Lewis Research Center	General Dynamics Convair Division.
	Goddard Space Flight Center	McDonnell-Douglas Astronautics Co.
Launch operations	Kennedy Space Center	General Dynamics Convair Division.
Mission operations	Ames/Pioneer Project Office	Ames/Pioneer Project Office.
Tracking and data acquisition	Jet Propulsion Laboratory	Deep-Space Network.
Data processing	Ames/Pioneer Project Office	Nonpersonal services support contractor.

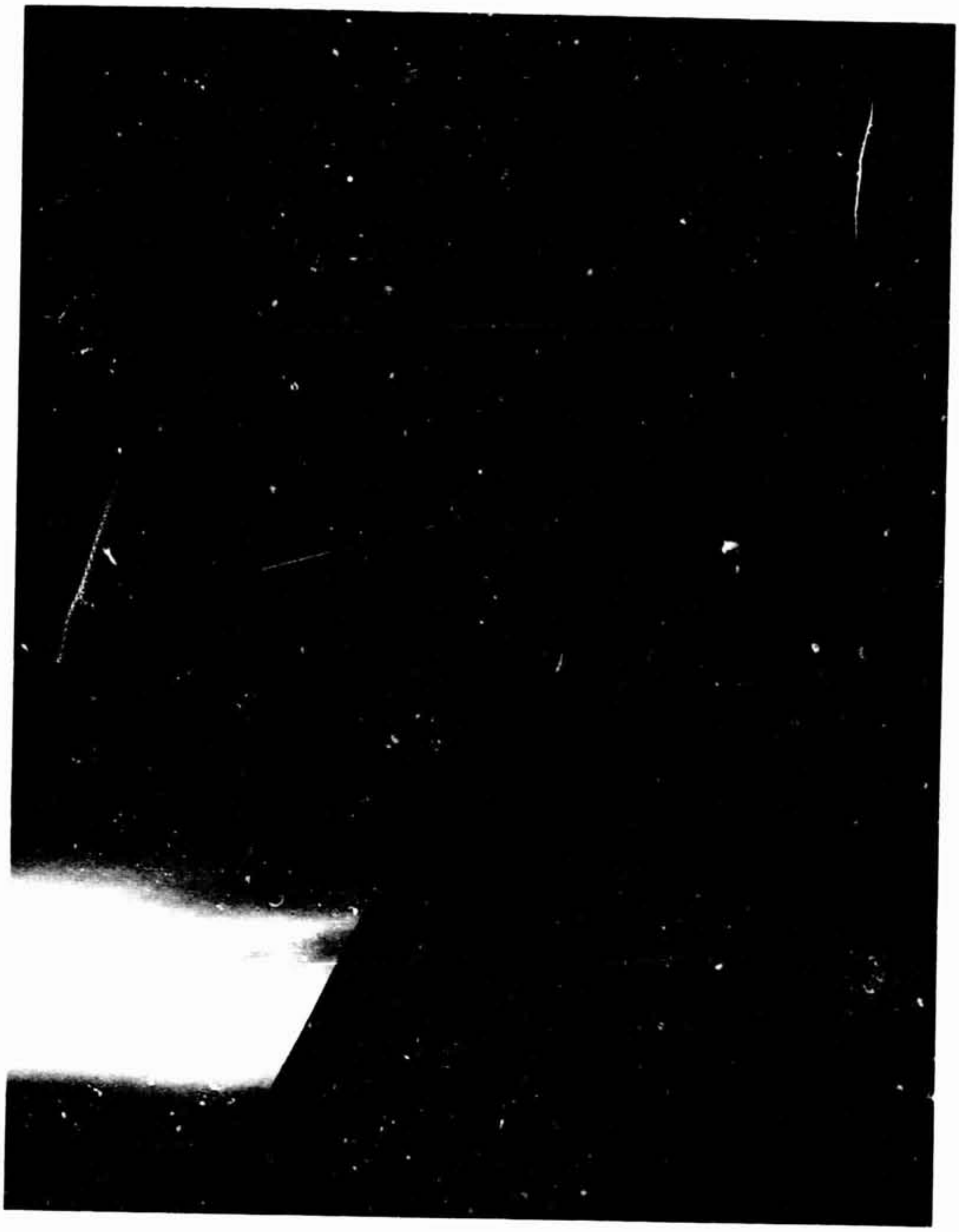


FIGURE 27.—Three 210-foot antennas like this one near Goldstone, Calif., will be used to communicate with Pioneers F and G. The others are near Madrid, Spain, and Canberra, Australia. They will operate in shifts as the Earth turns on its axis.

flight trajectory will be essentially a direct ascent to the desired conditions for departure from the orbit of the Earth for the orbit of Jupiter. The shrouding around each Pioneer will be jettisoned by firing explosive bolts after it has left the Earth's atmosphere.

Throughout the many months that each spacecraft is far from the Earth, the Deep Space Network will be used for tracking and data acquisition. That network has tracked Pioneers 6 and 9 nearly 190 million miles away from the Earth successfully. To follow Pioneers F and G at greater distances, it will use both its 85-foot antennas and three 210-foot antennas (fig. 27). At the climactic hours of the mission, the distances between those antennas on the Earth and the spacecraft will be so great that to query the vehicle and receive a reply will take 90 minutes.

DATA DISTRIBUTION

The Deep Space Network will forward data as it is received to the operations facility at the Jet Propulsion Laboratory operated for NASA in Pasadena by the California Institute of Technology, where a master data record will be kept on magnetic tape. That laboratory will have an advanced central data processor which will be used in connection with an interplanetary flight for the first time. Ames Research Center will be connected with the operations facility by high-speed data lines, and have standby computing capability.

Scientists at the Ames Research Center and many other noted laboratories will reduce and analyze the transmissions to extract the scientific data for particular purposes from the great quantity that is anticipated. These participants will include the Jet Propulsion Laboratory, the University of Chicago, the University of Iowa, the University of Southern California, the Dudley Observatory, the California Institute of Technology, the General Electric Co., and NASA's Goddard Space Flight Center and Langley Research Center.

More interplanetary spacecraft have been sent out from Russia than from the United States, but none to Jupiter. Greater international cooperation in space is one of the six specific objectives enunciated March 7, 1970, by President Nixon for our country's program. In furtherance of that objective, findings in all of the experiments to be undertaken on the Pioneer mission to Jupiter will be made available in appropriate ways, as promptly as possible, to theoretical and experimental scientists throughout the world.

"The universe," one astronomer, Carl Sagan, has written, "is vast and awesome and for the first time we are becoming a part of it."

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Seven centuries ago, a Persian artist depicted Jupiter as a source of knowledge.